Control ENGINEERING

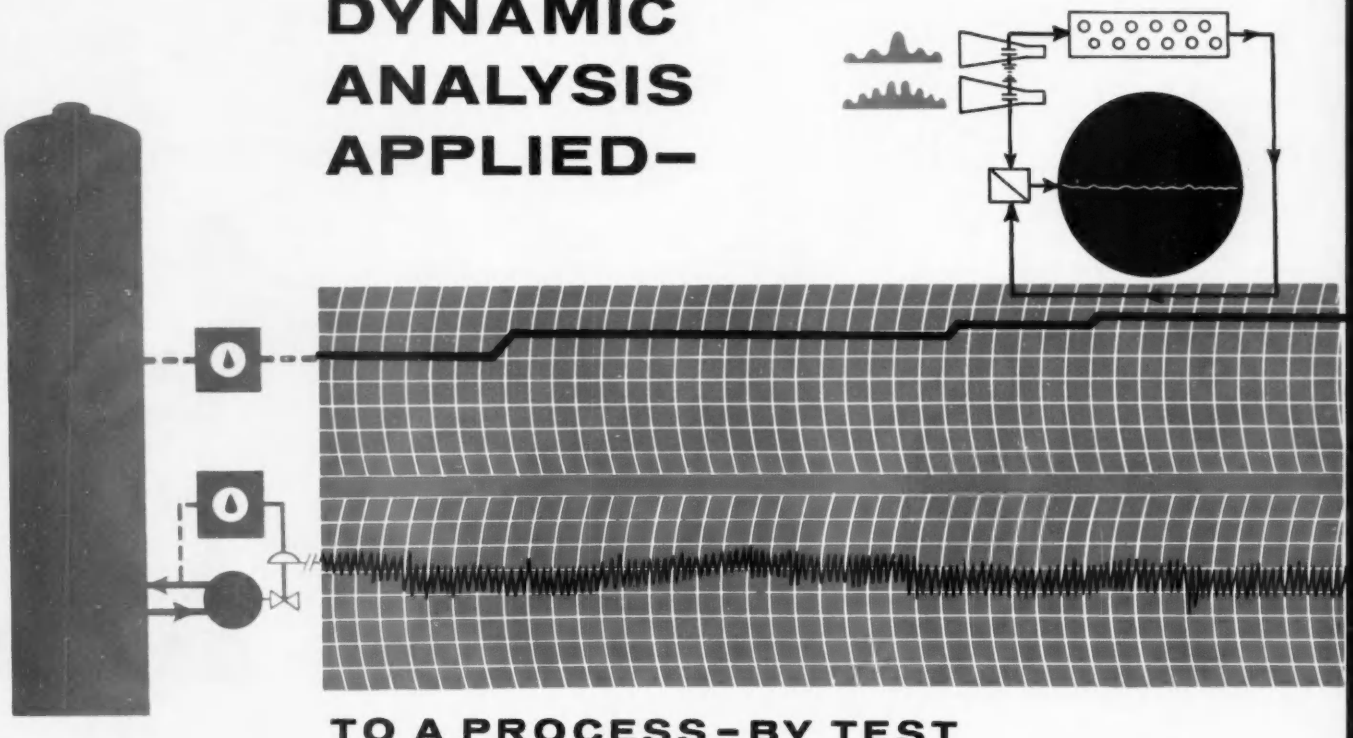
INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A McGRAW-HILL PUBLICATION

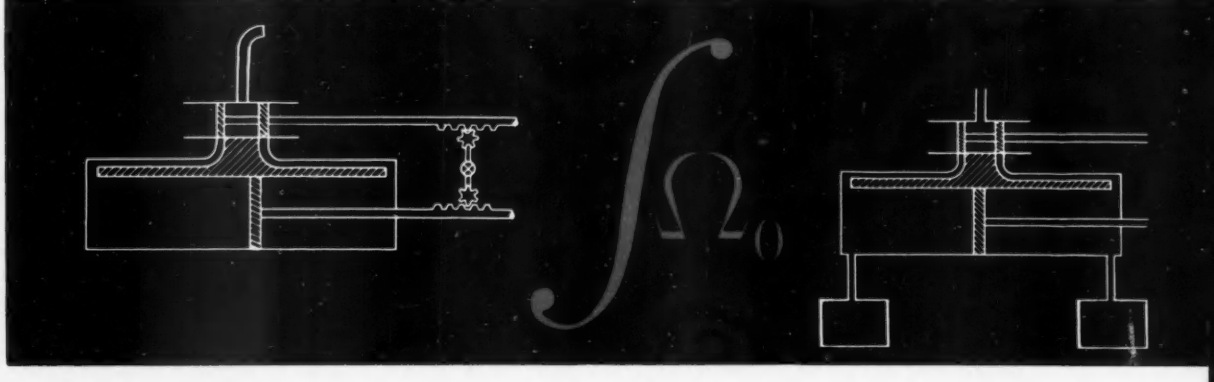
PRICE 50 CENTS

JUNE 1955

DYNAMIC ANALYSIS APPLIED–



TO A PROCESS–BY TEST



TO A PRODUCT–BY MATH

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from one thing to another

One standard to follow in selecting a designer for your specialized electronic control systems is to choose a firm that builds its *own* components for the control systems it makes. Librascope, Inc. manufactures such diverse electronic components as read-record heads, drums, magnetic amplifiers, flip-flop cards, packaged circuitry, analog-digital converters and other devices for sub-assemblies in its own military and commercial systems packages. This versatility of "turning with ease from one thing to another" indicates a competence for overall systems design acquired through nearly two decades in computer-control manufacture. Such highly specialized experience is available for the solution of your data-handling or computer control project. Inquire today.

Librascope also manufactures mechanical and optical components for computers and controls. Send for booklet describing the company.

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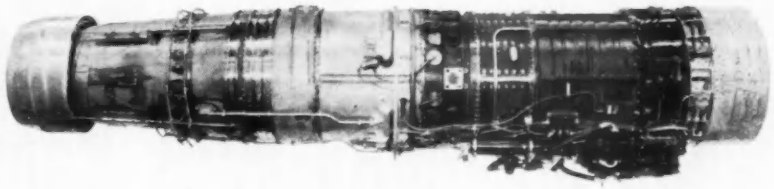
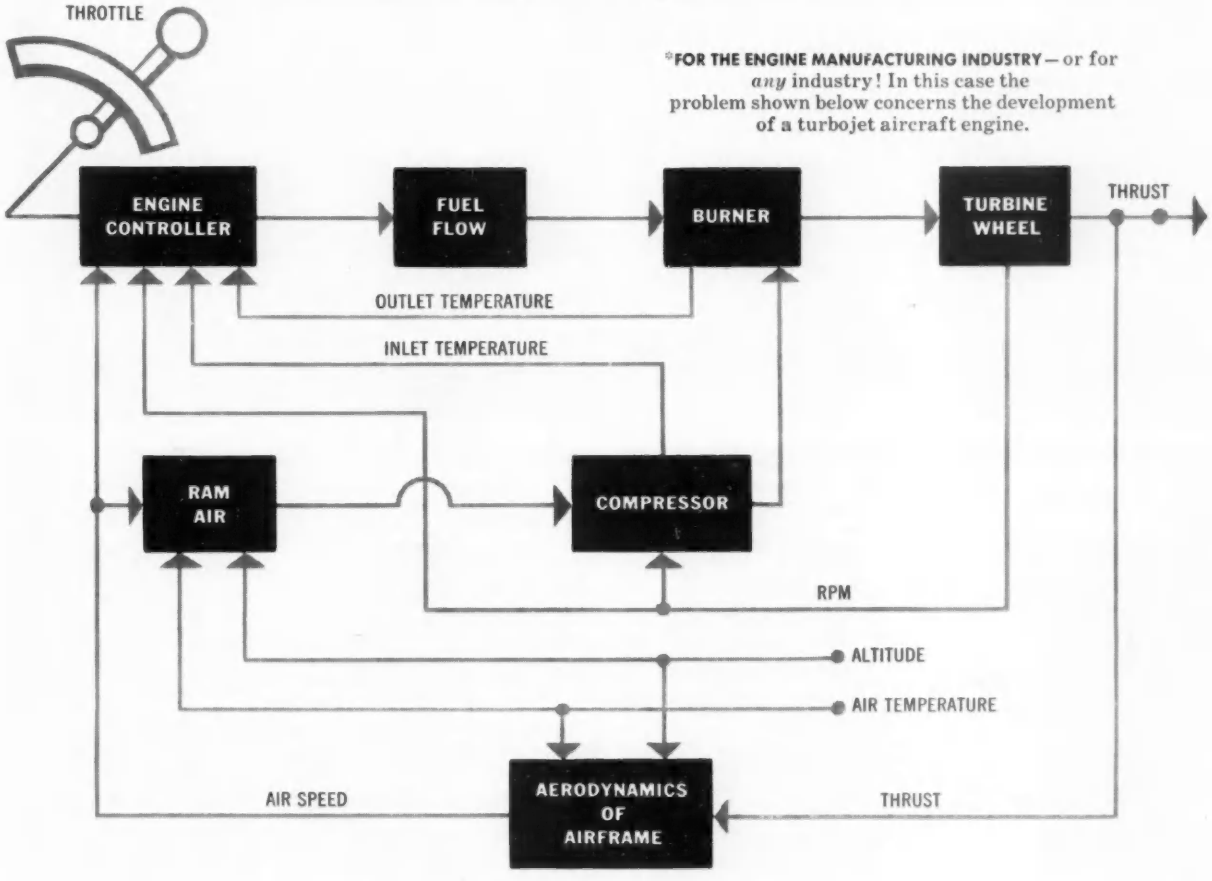
GEDA



*solves control problems**



***FOR THE ENGINE MANUFACTURING INDUSTRY**—or for *any* industry! In this case the problem shown below concerns the development of a turbojet aircraft engine.

EVEN though you may not be in the aircraft engine business, chances are the problem set-up above may be similar to one facing you right now.

But in any case, *the big point is:*

GEDA—versatile analog computing equipment built by Goodyear Aircraft Corporation—can step-up the analysis and solution of difficult automatic control problems, can eliminate empirical "guesswork" for creative engineers and designers *in ANY industry.*

Once you have programmed your problem on the GEDA problem board, wonderful things begin to happen in a fraction of the time it would take via conventional methods.

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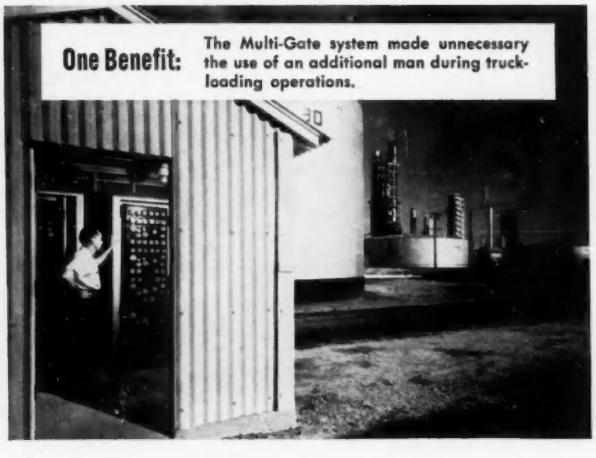
GOODYEAR AIRCRAFT

GEDA—T. M. Goodyear Aircraft Corporation, Akron 15, Ohio

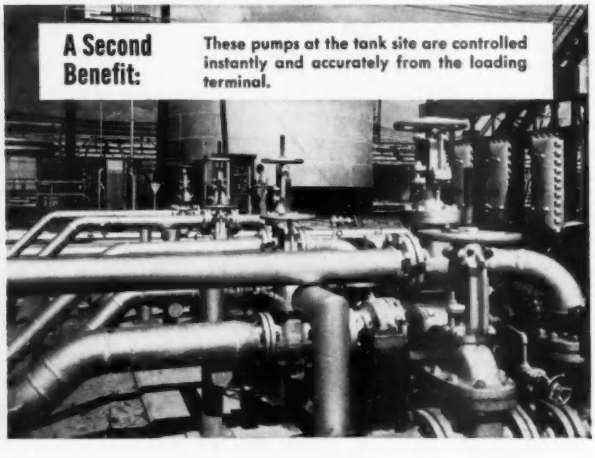
Operating costs cut, efficiency up when Magnolia adds Hammarlund COC*

The Problem: To build a new truck-loading terminal outside the congested refinery tank area.

The Answer: A Hammarlund push-button control system for turning the remote pumps on and off.



One Benefit: The Multi-Gate system made unnecessary the use of an additional man during truck-loading operations.



A Second Benefit: These pumps at the tank site are controlled instantly and accurately from the loading terminal.

The Magnolia Petroleum Company planned to build a new truck-loading terminal at its Beaumont, Texas refinery. They wanted it built outside the congested tank area.

Separating the truck-rack from the tanks and pumps, however, would make it necessary to add an additional man per shift. Also, the operations at times—especially in bad weather—would have to wait for this man to move from one pump location to another.

After installing the Multi-Gate remote control equipment, designed and furnished by Hammarlund, the truck-rack operator now has only to push a button corresponding to the type of fuel required. The remote pumps at the tank sites are activated and the required fuel is immediately obtained at the truck-rack. As a result, it was unnecessary to employ the additional man per shift, and it also eliminated the possibility of human error in telephone orders.

According to John Petkovsek, Senior Engineer and Supervisor of Communications and Electrical for Magnolia, other benefits of the Hammarlund system were:

1) Audio tones made it possible to perform many functions using a single telephone line, thus reducing the monthly rental costs. And without the dangers of DC pulses.

2) The system can be extended any time without additional communication lines, or it could be operated over radio or microwave without change.

This is another example of the Hammarlund concept of Centralized Operations Control* at work. Write to Hammarlund, 460 West 34th St., New York 1, N. Y. *for details on COC. Ask for Bulletin CC-10*

*Trademarks pending on *Centralized Operations Control* and COC.

Control ENGINEERING

JUNE 1955

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

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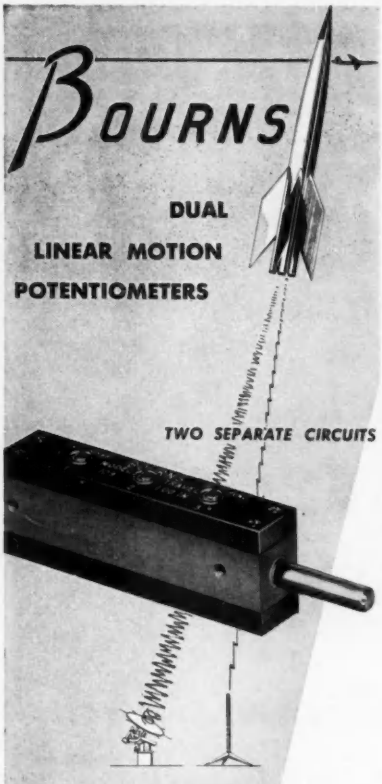

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AND
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Technical Bulletin on request, Dept. 279

SHOPTALK

IDEA HATCHING IN PHILLY

Jim Reswick's calm approach to dynamic analysis (see p. 50) was first aired to editors and friends in our Philadelphia hotel room during last fall's ISA conclave.

Jim waved his hand to make a point. It caught. We rushed it into print. And two of our guests made plans to try it in their plants.

HARRY UNHARRIES US

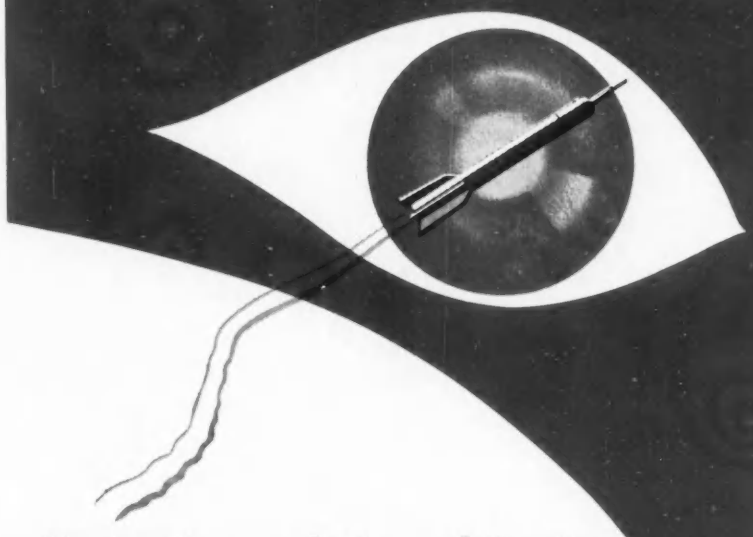
Covering control, we find, takes uncontrolled time, travel, and typing. Our ubiquitous editors have had little left for family and farm. But things now look bright for an occasional Sunday off. Harry Karp, formerly an engineer for Thomas A. Edison, Inc., joins us as Assistant Editor with this issue. His able head, hands, and overnight bag are a happy addition.

HAIL, HAIL THE GANG'S NOT QUITE HERE

The picture below almost captured our whole staff during a recent monthly editorial meeting. This makes it a near-collector's item. Missing were By Ledgerwood and Consulting Editors Gene Grabbe and Marion Long. All three were on the West Coast.

Seated from left to right: Editorial Assistant Sue Richmond; Editor's Secretary Joen Ciglar; Managing Editor Lloyd Slater; Editor Bill Vannah; Publisher Will Garey; Secretary Doris Hansen; Secretary Sal Swanda. Standing from left to right: Promotion Man Harold Olson; Assistant Editor Ray Auger; Consulting Editor Gordon Brown; Consulting Editor Keith Henney; Ex-Staffer George Boehm; Consulting Editor Dave Rubinfien; Assistant Editor Ed Kompass; Production Manager Wally Carmichael; Art Director Jack Gordon; Copy Editor Warren Kayes.

hitch your missile to a star . . .



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Photoelectric Sextant

FOR CONTROL

proven components now in production

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SPECIAL TEST EQUIPMENT optical and electromechanical for flight test observations.

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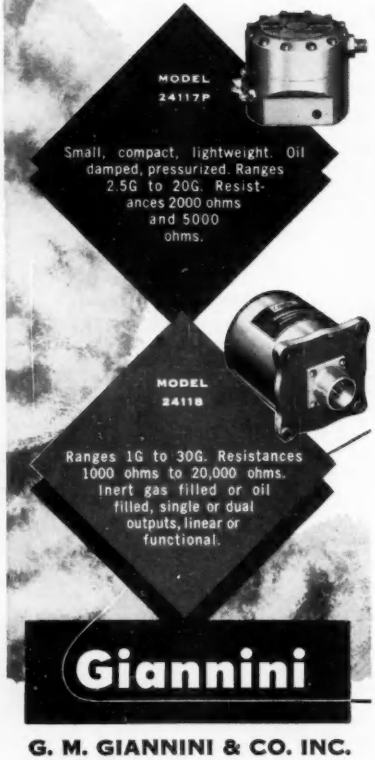
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PASADENA 1, CALIFORNIA

FEEDBACK

To the Editor—

Dr. N. Minorsky's Patent 1,436,280, "Automatic Steering Device," is really a remarkable document, with ninety-five claims. Look at the last page, particularly Claim 91. Everybody infringed it while it was alive, and I think it deserves real comment.

Albert F. Sperry
Panellit, Inc.
Skokie, Ill.

We agree. Here is Claim 91:

"The method of maintaining the conditions of relative movement of two elements constant, which consists in controlling the conditions in response to the extent of departure of the conditions from that desired, and to the values of a plurality of higher derivatives with respect to time of this departure."—Ed.

Whipping Post

To the Editor—

. . . I remind you that Control Engineering does embrace the subject of mechanical controls and especially some of those highly specialized products which have been developed but which seem to be overlooked in the editorial pages of your excellent publication.

Two parts in fun and one part in earnest I admonish you . . . to "broaden your scope" and pay some attention to mechanical controls, even though they may be the ugly duckling of the control family and lack the glamor and romance offered by some of the younger sisters of the family.

Cameron Chisholm
Teleflex, Inc.
North Wales, Pa.

As a start you will find in our May issue an article on mechanical means of generating control functions. The article is by Prof. John Gibson, Yale University.—Ed.

Reactor Rectifications

To the Editor—

Your mention of ALCO's award for a locomotive power plant in your Feb-

PROBLEM FORUM

Here is a measurement problem that should yield readily to the experience of our readers. Remember that we pay cash rewards for interesting problems and outstanding solutions. This month's winner—Number 5.

Herr Apparatebau wants your help. He is seeking facts on flow integration. Can you supply some answers? We'll supply a cash prize for the best one.

To the Editor—

A flowmeter (rotameter principle) measures a flow rate. The measurement is converted to a 0 to 30 mv (100 ohms) signal. The problem is to determine the *entire* volume during an interval of time (for instance, during 24 hours) and to transmit to the integral to a recorder. What circuits and meter types would be suitable? Keep in mind simplicity and reliability.

Heinrichs Apparatebau
Koeln-Lindenthal, Germany

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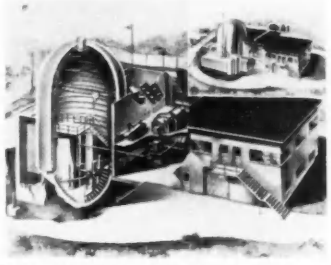
ruary issue was in error. Actually, our award was for the Army Package Power Reactor, a land-based, atomic-driven electrical power plant, components of which can be transported by air to remote locations anywhere in the world. I am enclosing an artists conception of APPR.

Dana T. Hughes
American Locomotive Co.
Schenectady, N. Y.



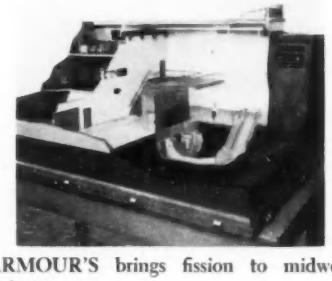
ALCO's land-rooted, but air-borne reactor.

To the Editor—

On page 20 of your April issue you have an article on American Machine and Foundry's claim to "the first private research reactor." As early as last September we announced that Armour Research Foundation of Illinois Institute of Technology was building the nation's first private research reactor. You should have received a press kit with additional info.

Work will begin in April on the reactor and it will be operating by the end of the year—much earlier than AM's plans.

Victor J. Danilov
Armour Research Foundation
Chicago, Ill.



ARMOUR'S brings fission to midwest industry.

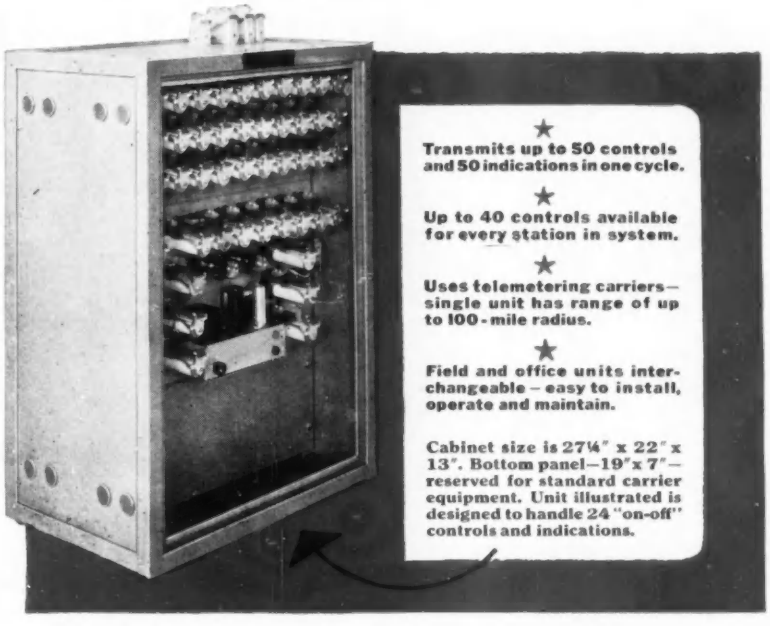
Here we go again. A release in the mail to us last week says that the "world's first industry-owned, nuclear materials test reactor will be built by Westinghouse Electric Corp., in Pittsburgh." Any reactions to this latest reactor?—Ed.

South African Engineer

To the Editor—

"As a man taking an education in servomechanisms to a country whose

Now...a new low-cost system for remote control of "on-off" functions


★
Transmits up to 50 controls and 50 indications in one cycle.
★
Up to 40 controls available for every station in system.
★
Uses telemetering carriers—single unit has range of up to 100-mile radius.
★
Field and office units interchangeable—easy to install, operate and maintain.
Cabinet size is 27¼" x 22" x 13". Bottom panel—19" x 7"—reserved for standard carrier equipment. Unit illustrated is designed to handle 24 "on-off" controls and indications.

HERE'S an all-new patented remote control system that will operate any "on-off" functions from a central point and give "report back" indications as soon as the function has been completed. This new system has been thoroughly tested and proved during five years of research and development. It has been further proved by more than a year of actual operation on a major railroad application where it has performed perfectly.

Simple, practical and efficient, this new system makes use of the multiplex principle. Any telemetering carrier capable of transmitting 7 or more impulses per second can be used. Circuit set-ups are easy to understand and operate, eliminate the need for highly skilled maintenance men. Field and office units are interchangeable. The use of commercially available carriers eliminates the need for line batteries. Only three types of relays are used . . . and the number of relays required is minimized by the use of stepping switches. All major parts are of plug-in construction, easy to remove and replace.

If you have a problem in remote control of "on-off" functions—regardless of the type of industry or application—this new system may be the answer. Initial cost of equipment and installation is comparatively low. Maintenance expense is negligible. Usually this system can be superimposed over existing transmission media eliminating the need for new line wires.

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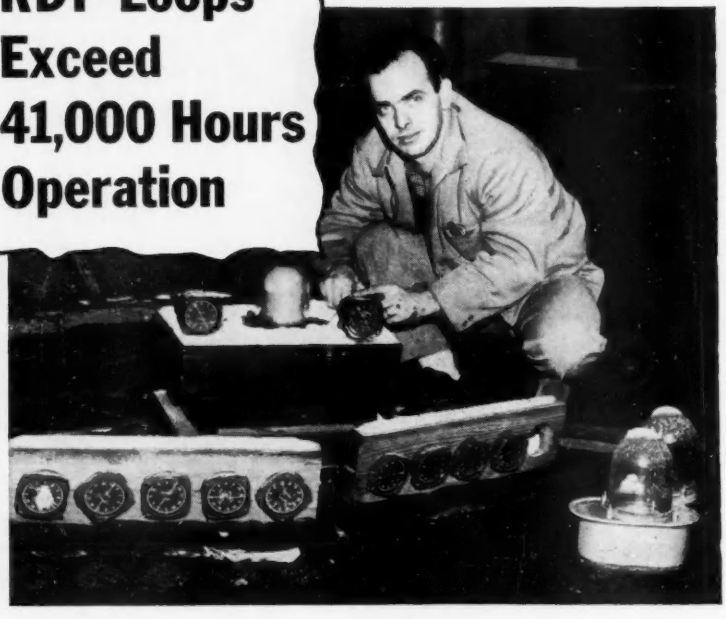

The Kearfott AS-313 Radio Direction Finder Loop and the ID-90 Indicators withstood continuous operation for 41,977 hours. This is over 40 times the 1,000 hours required by Air Force specifications for Sealed Aircraft instruments.

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FEEDBACK

industrial development is just getting underway:"

(a) We are still building up a dynamic control and analysis laboratory . . . also an analog computer to be used to a great extent on servo problems.

(b) Our publications have been intended to acquaint South African readers with the philosophy of automatic control.

(3) Your publication is still comparatively unknown here and still not available in the C.S.I.R. library.

J. C. R. Heydenrych
South African Council for Scientific and Industrial Research
Pretoria, South Africa

Mr. Heydenrych's group has built an improved mass-spectrometer . . . "with a servo-system for controlling the electromagnet's speed of response and stability." Indicative of their broad interests, they will soon publish (in a local journal) an article on an "automatic and continuous weigher designed for and installed at a South African chemical factory.—Ed.

Mill Control Minded

To the Editor—

In the March 1955 issue of Control Engineering there appeared a very fine article, "Automatic Mill Control," by Mr. Carl Vossberg.

I would like to obtain a textbook on steel mill controls and one dealing with paper and plastic mill controls. Could you supply me with the titles and publishers of books of this type? . . . Are there any periodicals dealing with the design, construction, and operation of various types of mills?

John W. Leahy
Wethersfield, Conn.

We suggest that you investigate the following:

1. "Magnetic Control of Industrial Motors," G. H. Heumann, John Wiley & Sons, Inc., New York.

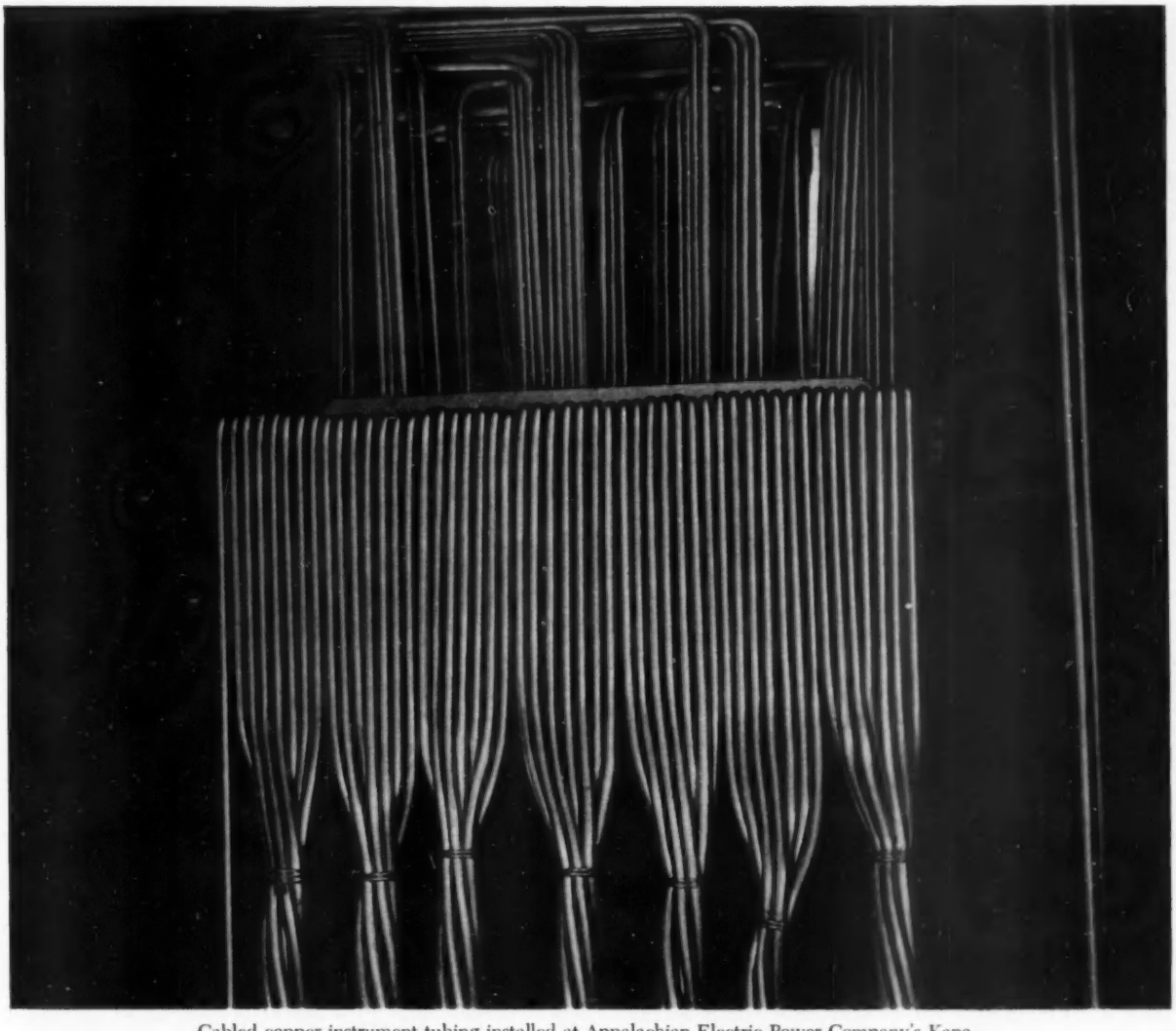
2. Section 17, Industrial and Commercial Power, "Standard Handbook for Electrical Engineers," Archer E. Knowlton, McGraw-Hill Book Co., Inc., New York.

3. "Westinghouse Engineer," particularly the article, "Magnetic Amplifiers in Industry," Vol. 10, pp 201-205, Sept. 1950.

4. "General Electric Review," particularly articles by W. E. Beadle.

5. The technical bulletins of Allis-Chalmers, Cutler-Hammer, etc.

6. Watch for forthcoming articles in Control Engineering. —Ed.



Cabled copper instrument tubing installed at Appalachian Electric Power Company's Kanawha River Station. You see it at the point where the cable divides for run-outs to instruments. Note smooth, short-radius bends.

108,000 feet of cabled copper instrument-control tubing helps keep Kanawha River Power Station humming

Hundreds of air-actuated instruments are an important part of the instrumentation control network at the 430,000-kw Kanawha River Station of the Appalachian Electric Power Company – part of the American Gas and Electric System. The size of the plant called for instrument tubing runs of up to 1,000 feet – with tubing cabled in bundles. For economical stranding, the tubing was needed in unusual lengths – without joints. To conserve space, small diameter tubing was needed. And ability to take short-radius bends without pinching was necessary.

The 108,000 feet of Anaconda Seamless Copper Tubing was supplied in 1,000-feet lengths. Outside diameter was only ¼-inch, wall thickness only .030". Shown above are typical tube bundles as they near terminal connections.

Anaconda small-bore, thin-wall tubing is available in lengths up to 2,400 feet. It comes in long coils on reels, or cut to your requirements. Capillary tubes, restrictor tubes, Bourdon tubes, special shapes, and fabricated tubes and parts for refrigeration and air-conditioning are available in many different alloys. These include phosphorized and OFHC copper, the full range of brasses, 3,003 aluminum, nickel silvers, and certain special alloys. For more information about Anaconda small-bore tubes and special shapes ask any district sales office, or write direct to *The American Brass Company, Waterbury 20, Connecticut.* In Canada: *Anaconda American Brass Ltd., New Toronto, Ontario.* 5578

Some of the many sizes and shapes of Anaconda Small-diameter Tubes.

ANACONDA®
SMALL DIAMETER TUBES

if you need signs like this

DANGER
NO SMOKING

because of explosion hazards...

it'll pay you to look into **Adlake**

mercury relays

Adlake relays require no maintenance whatever ...are quiet and chatterless...free from explosion hazard. Dust, dirt, moisture and temperature changes can't affect their operation. Mercury-to-mercury contact gives ideal snap action, with no burning, pitting or sticking. Time delay characteristics are fixed and non-adjustable.

Adlake 98th year of serving the transportation and building industries

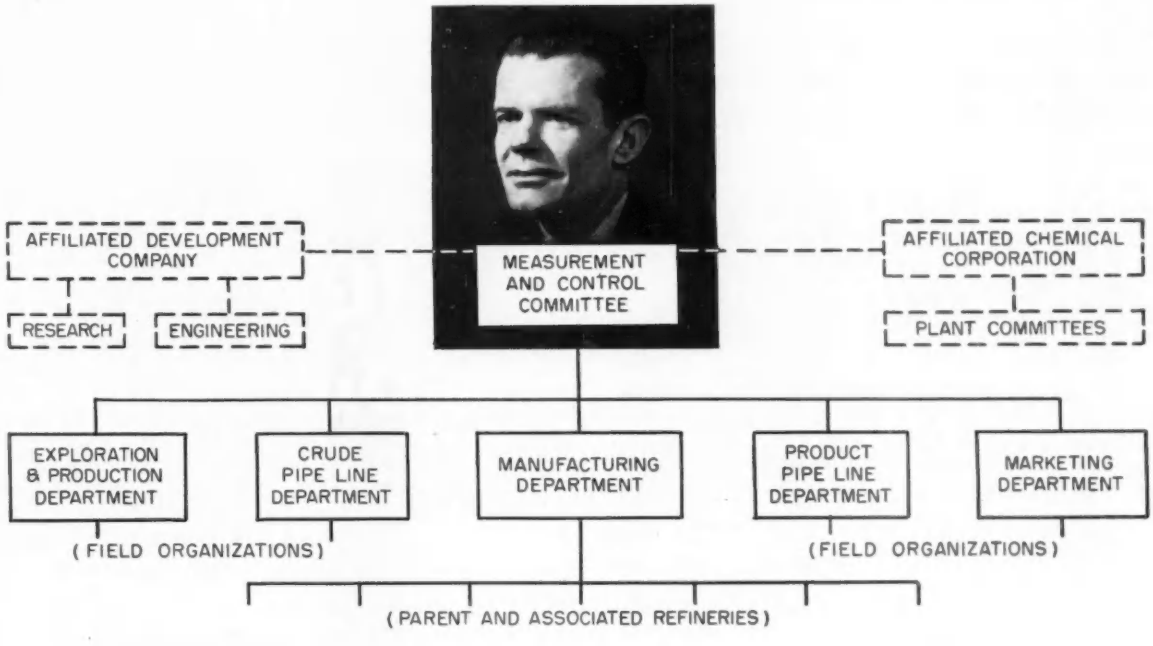
The Adams & Westlake Company

Established 1857 • ELKHART, INDIANA • New York • Chicago

the *original* and largest manufacturers of mercury plunger-type relays

A CONTROL PERSONALITY

JIM KERLEY
Paces Instrument-Consciousness



J. G. Kerley is an example of the control engineer who literally rose through the ranks during the budding stages of process instrumentation. Now Senior Engineer for Instruments in the Manufacturing Dept. (Refineries) of Shell Oil Co., he followed an upward path that little resembles the ones trod by today's graduates of engineering schools.

This is not Jim's only achievement. He is also chairman of Shell Oil's Measurement and Control Committee, a group of engineers whose function is to promote the use of measurement and control equipment in Shell Oil Co., its affiliated chemical company, and its Canadian associate.

An honor graduate of Mississippi State in electrical engineering, Jim started his "professional career" as a mechanic's helper at Shell's Houston refinery during the depression year of 1933. He championed instrumentation so convincingly that in 1937 the refinery made him foreman of its first instrument department. Since there were no instrument men available within the company, he had to staff with pipe-fitters and electricians recruited from the maintenance department and trained by himself.

During 1937-38 Jim conducted two instrument schools at the refinery and after the outbreak of World War II he taught extension instrument courses at Houston under the auspices of Texas A & M. Early in 1943, after ten years of in-plant instrument work, the refinery appointed him an Instrument Engineer.

In January, 1945, Shell's top management set up the Measurement and Control Committee and called Jim to New York to be its chairman. The Committee represented management's recognition of the need for instrumentation and automatic control. It has since been a vehicle to encourage instrument-consciousness in every phase of Shell's widespread operations, from exploration to marketing.

As chairman of the M&CC, Jim is contact man in the departments of exploration and production, crude pipe lines, manufacturing, products pipe line, and market. He disseminates information on new equipment, consults on experimental application problems, and administers the Committee.

Sources of problems as well as information on developments are the refineries and operating field organizations, where new equipment is tried out. If a department needs a non-existent device, Jim's Committee determines whether the device must be designed. If so, it turns the job over to the research section of Shell Development Company.

Operation of Plant-Scale Installations* DEMONSTRATES BENEFITS OF ELECTRONIC PROCESS CONTROL

'American-Microsen' Electronic Process Control Installations Now In Successful Operation Have Proved The Reliability, Speed, Sensitivity And Accuracy Of This Modern Concept Of Process Instrumentation.

This is the electronic process control system that now makes it practicable to utilize the capabilities of process equipment far more fully than ever before. Revealed in actual operation of plant-scale installations are the much discussed benefits of this new approach to plant instrumentation.

Used to *measure, indicate, record and control process variables* (pressure, differential pressure, temperature, level flow, pH, gas analysis, etc.), these installations exhibit every essential to improve product quality, increase operational efficiency and plant productivity.

Only the 'American-Microsen' System provides:

Lag-free signal transmission using the simplest communication lines.

Extremely fast, accurate measurements and control responses — sensitivity impossible to duplicate in other types.

Installation of all controllers in the instrument room *any distance from the process* — even 30 miles or more.

High stability that permits use of narrower proportional bands.

Freedom from dirt, leakage, freeze-ups and other transmission line problems.

Standardized control components interchangeable at the panel and plug-in components on each instrument.

Adaptability — more than one input circuit can be fed into a controller for cascading or programming.

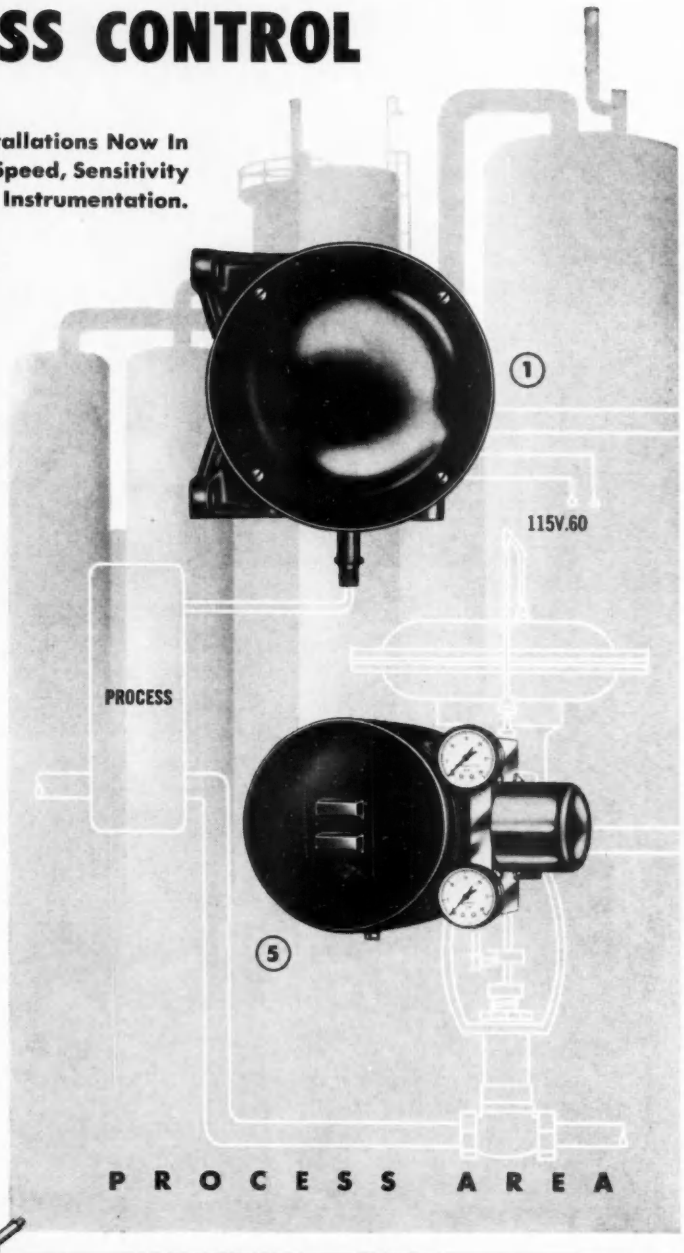
DC signal that can be fed to potentiometer recorders, digital read-out systems, monitors, computers, etc., so that process and operational data are automatically reduced to quickly usable form.

Flexibility — output signal can be fed in series to any number of receivers, without impairing accuracy. Components can be mounted anywhere convenient to operating and servicing.

Electrical circuitry makes possible unusual control and measurement functions not available in mechanical systems.

Minimum installation or maintenance investment in transmission lines, air compressors, filters, pressure regulators, dryers.

**Names and locations of installations available upon request.*

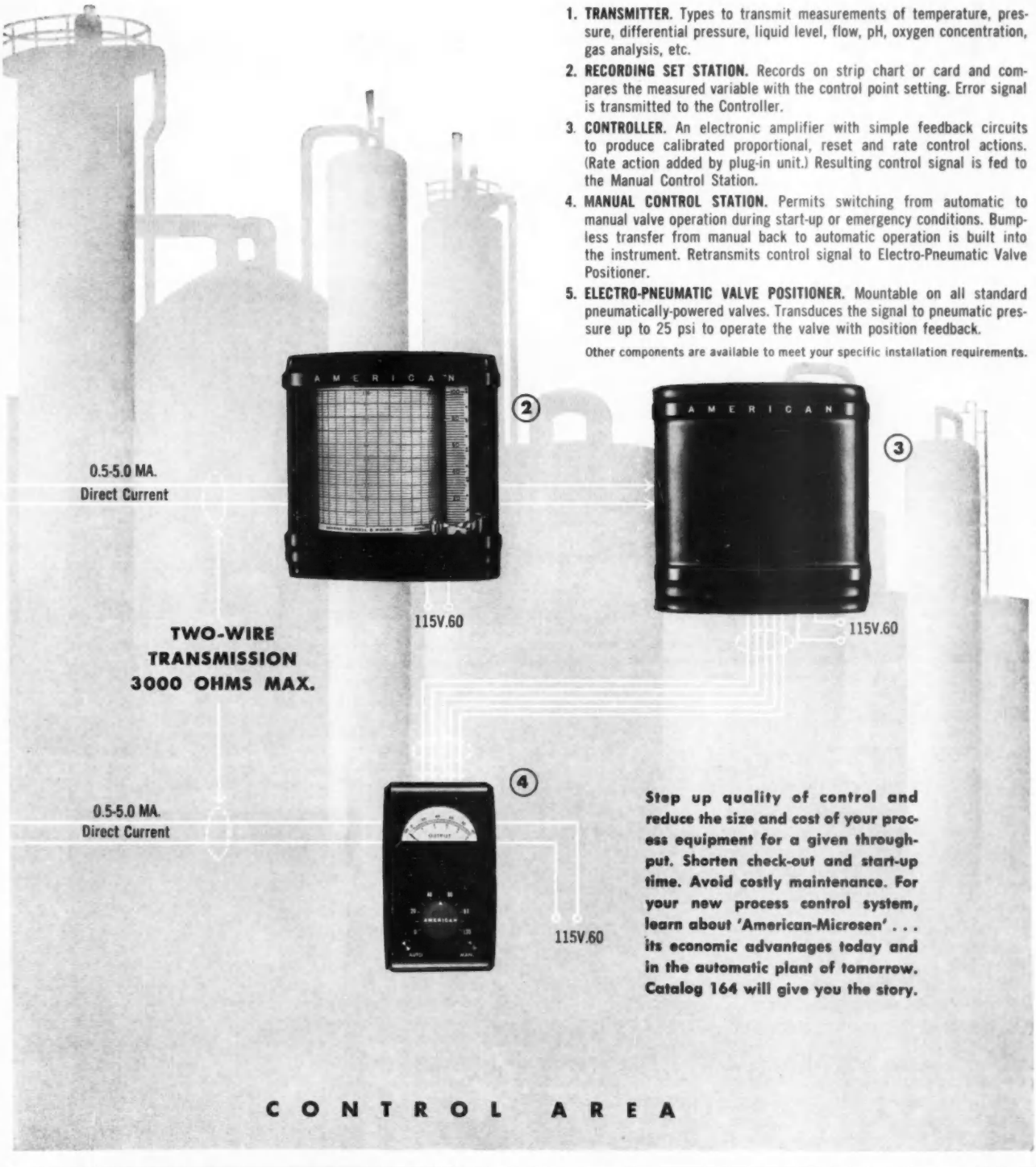


THE 'MICROSEN' BALANCE, the "nerve center" of 'American-Microsen' Instruments, is a simple, electro-mechanical servo-mechanism. It operates on the force-balance principle to produce a high-level direct current signal that is not affected by any normal electrical or ambient condition.

MANNING,

1. **TRANSMITTER.** Types to transmit measurements of temperature, pressure, differential pressure, liquid level, flow, pH, oxygen concentration, gas analysis, etc.
2. **RECORDING SET STATION.** Records on strip chart or card and compares the measured variable with the control point setting. Error signal is transmitted to the Controller.
3. **CONTROLLER.** An electronic amplifier with simple feedback circuits to produce calibrated proportional, reset and rate control actions. (Rate action added by plug-in unit.) Resulting control signal is fed to the Manual Control Station.
4. **MANUAL CONTROL STATION.** Permits switching from automatic to manual valve operation during start-up or emergency conditions. Bumpless transfer from manual back to automatic operation is built into the instrument. Retransmits control signal to Electro-Pneumatic Valve Positioner.
5. **ELECTRO-PNEUMATIC VALVE POSITIONER.** Mountable on all standard pneumatically-powered valves. Transduces the signal to pneumatic pressure up to 25 psi to operate the valve with position feedback.

Other components are available to meet your specific installation requirements.



Step up quality of control and reduce the size and cost of your process equipment for a given throughput. Shorten check-out and start-up time. Avoid costly maintenance. For your new process control system, learn about 'American-Microsen' . . . its economic advantages today and in the automatic plant of tomorrow. Catalog 164 will give you the story.

MAXWELL & MOORE
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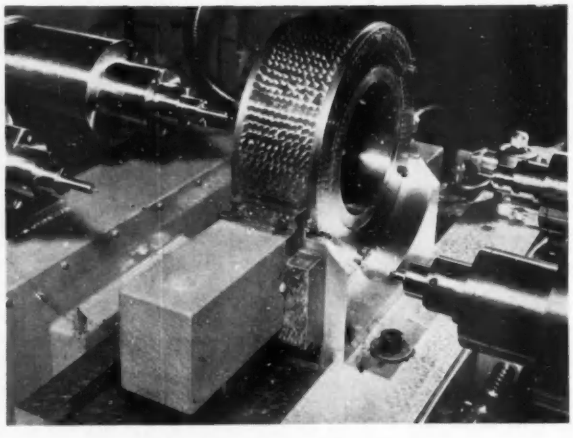
INDUSTRIAL CONTROLS DIVISION

Stratford, Connecticut

MAKERS OF 'AMERICAN-MICROSEN' ELECTRONIC TRANSMITTERS, INDICATING OR RECORDING SET STATIONS, CONTROLLERS, MANUAL CONTROL STATIONS AND ELECTRO-PNEUMATIC VALVE POSITIONERS.

Tape-Controlled Machining Nears the Average Plant

HERE . . .



Tape for Honeywell's automatic boring machine in background is being programmed by the punch-key operator. It will guide linear travel of the hydraulic slide (lower left in picture at right) and rotary motion of the central holding fixture.

M-H REGULATOR CO. now bores gears automatically

Long one of the prime vendors of automatic control, Minneapolis-Honeywell decided to try some of its medicine on itself. The result was a rewarding self-appraisal in ways to automatically produce its automatic equipment—and a pioneer application of tape-controlled principles to a precision boring machine.

The initial step in Honeywell's job of self-appraisal was to wean some of its top control engineers away from customer problems and turn them loose in the throbbing Minneapolis factory. What they saw convinced them that automatic control could also be preached—and practiced—at home. The first tangible move was a new Automation Section in factory engineering with John Rudolph at its helm.

Honeywell couldn't lose. One of the first achievements of John's group was an automatized boring machine that saves time and increases precision. And the potential for the section's tape-controlled system is so grand that the company has given it a new title—Machine Control Development Group—and now offers its double-barreled know-how to outsiders on a fee basis.

The Honeywell system involves a standard four-spindle Excello precision boring machine modified with built-in electronic components and directed by a tape "reader" housed in an adjacent control cabinet. To operate, an adapter ring slips on the machine's rotary fixture, cutting tools mount on its four spindles, and the punched tape feeds into the "reader". The operator then inserts the work and pushes a button. When the part is bored the machine stops.

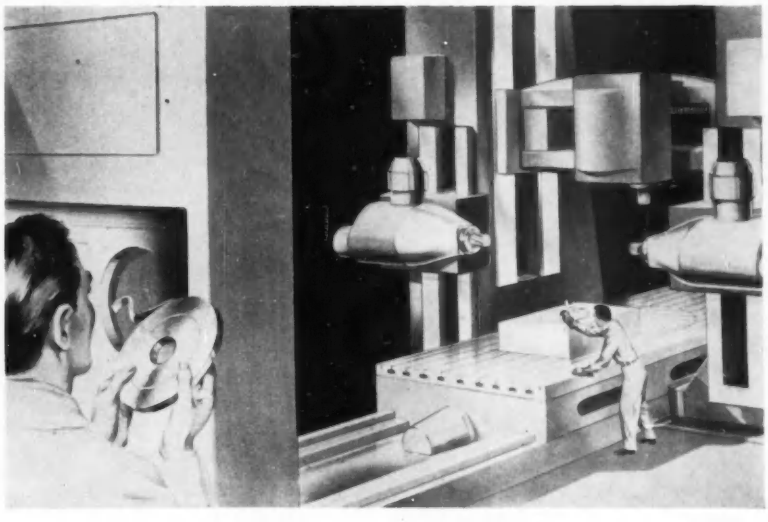
Hold coordinates and feed instructions are punched into the tape by a perforating machine similar to a typewriter. A tape can be programmed in five minutes and machine parts shifted within a half-hour.

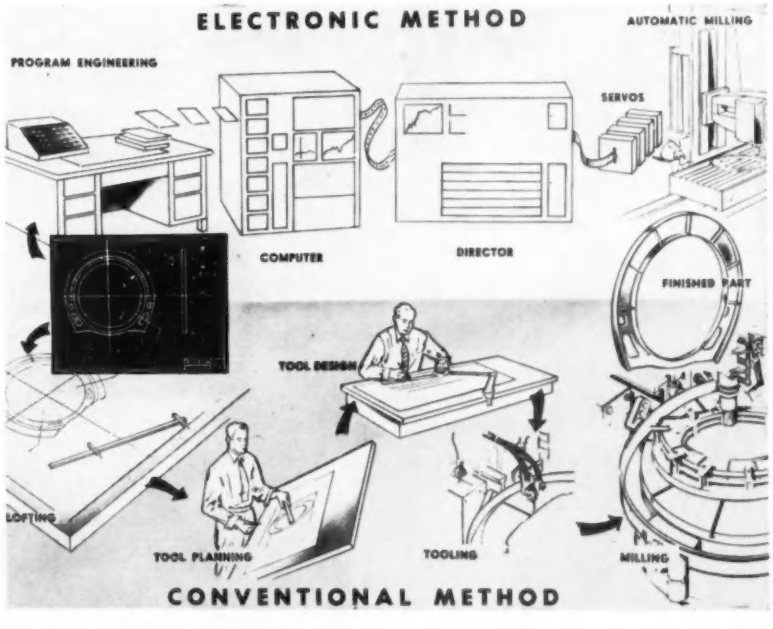
While this first borer only fashions shaft holes in precision instrument gears, Rudolph claims it can adapt to a variety of hold patterns and sizes. In any case, coordinate information is fed to the unit in 0.0001 in. increments over its eight inch linear range and 0.01 deg over its 36 deg rotary range. And its accuracy is better than plus or minus 0.0005 in.

John Rudolph feeds a strip of punched tape into the "reader". The knobs below manually adjust linear travel of cross slide and motion of holding ring.

. . . AND TO COME

Sometime in late 1956 the wonderous doings pictured below will become reality. The top sketch shows Convair's huge 200-ton tape-controlled milling machine and below it are the steps that show how digits apply from drawing to finished part.





CONVAIR DIVISION plans its automatic milling machine.

Tape-controlled aircraft production —on Goliath's workbench—is the aim of General Dynamic Corp.'s Convair Div. And the U. S. Air Force subscribes to this tall order. On March 27 it awarded a giant-sized $1,280,000 contract to Convair to design and construct the huge 200-ton, 18-axis milling machine which should revolutionize aircraft manufacture.

Aircraft engineers are frankly wowed by Convair's grandiose plans. The machine will sit on a 20-ft bed with 10-ft clearances. It will have two vertical and two horizontal cutting heads—all able to operate at the same time. It will feature a rotary turntable with variable speed. And it will be able to make 18 different selective motions.

One awed tool engineer summed it up: "We've been talking about developing a five-axis machine (we already have three-axis units). But this concept makes possible as many as 18 different motions with one machine—an operation so complicated no human could do it and still maintain quality."

The elaborate automatic control system for the machine is based on developmental work done at MIT, also under Air Force auspices. It involves the transfer of coded engineering dimensions and formula into coded binary or digital numbers using punched cards or a keyboard. Fed this information, a computer translates it into a punched-tape program. The tape then feeds into an electronic director which either runs the milling machine itself or produces a magnetic tape that will run it.

Convair and Air Force planners believe that the idea of running the final magnetic tape in a separate operating console may have many virtues. For one thing, it will free the computer-director for other activities such as controlling rolling mills, stretch presses, and profiling machines. For another, programmed tapes could be shipped around to run similar machines in other plants during an all-out war emergency.

The giant machine will be as versatile as it is dextrous. It will cut all aircraft metals, including steels and titanium, to any shape within the second degree curves of today's airframes. This includes wing spars and contoured bulkheads. What's more, the machine will actually sink aircraft dies.

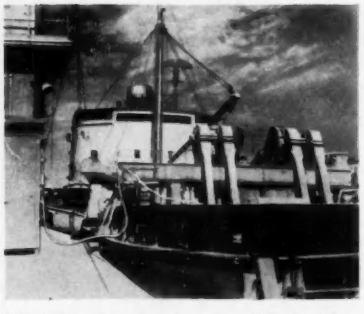
After a cutting head has obeyed a tape command and completed its metal-shaping task, it will retract and another head will move into place. The bed will engage automatically and stop at tape command, and the turntable will rotate until the part is finished.

Great economies are expected from the new production system. Prototype parts will be made quickly and easily and design errors corrected mathematically in the tape. If the prototype proves satisfactory, no retooling time will be necessary for the production airplane. And besides drastically cutting (by an estimated 85 per cent) tool engineering lead time, savings of $50,000 or more in producing just one part are envisioned through elimination of families of tooling.

The Convair machine and its control system are expected to be producing in the company's Plant II in San Diego by September, 1956.

Control Spurs Progress: ON LAND, ON SEA, IN THE AIR and underground

ON LAND on May 1 this Brush Electronics wagonful of sound measuring instruments started its nationwide tour of American plants.



ON SEA this doughty Swedish freighter carried its own automatic enclosed screw conveyors to bulk cement in and out of its hold.

IN THE AIR Convair's spanking new F-102A was packed with control to fit it for all-weather duties.

AND UNDERGROUND New York's venerable, rattling, jampacked IRT subway line will soon get new zip with a $9.7-million automatic traffic control.

Spring 1955 seemed to fire control engineers to some bustling new goals in speed, efficiency, and precision.

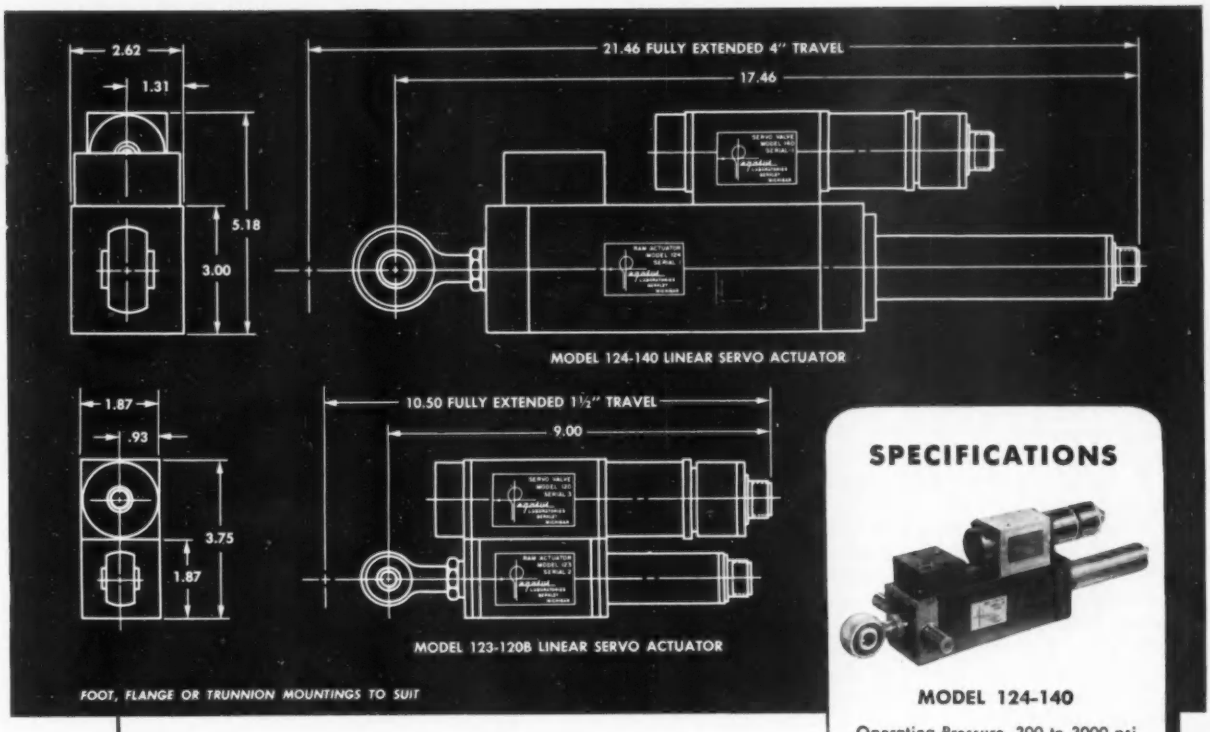
On land, automobiles and trains responded to the automatic age. Seattle, Wash., traffic came under the influence of radar. A busy intersection was equipped with detector units over the traffic lanes. Microwave reflections from the tops of passing cars were fed into a computer which did a grand job of spacing the red and green lights. Moriarity was off resting his feet.

In Connecticut, commuters on the New Haven Railroad got news that should make them happier about their lot. Alert President McGinnis signed up the road for a Teleregister electronic network that will handle up to 1,000 reservations per hour. The magnetic drum system, fed by leased wired, will speed a prospective passenger with accurate holds on his space anywhere in the line. Snorting commuters can then move up and buy their ten trip ticket in time to make the 7:43.

On sea, servo-operated stabilizers were rigged on several liners to reduce billiousness in Europe-bound landlubbers. But there were more practical nautical control developments, too. No one likes to haul cement out of the hold of a ship. So the Swedish engineering firm of Nordströms Libanor equipped three carriers of the Skanska Cement Corp. with neat systems of enclosed worm-screw conveyors to do the job. One man, making like a control engineer before a handsome panel inside the bridge, can load a 1,500-ton cargo in four hours, discharge it in eight. Levels of all holds and conveyor movements show up graphically on the panel.

In the air at least a dozen new aircraft and missiles thrust for new speeds and performance—each a tribute to control. The USAF's Hughes Falcon—the latest and "hottest" guided missile—zoomed aloft with guidance controls powered by matchbox-sized silver-zinc storage batteries that weighed only three ounces each. The tiny batteries, a product of Yardney Electric Corp. in New York, are rated at three amp hours. Incidentally, component size is important in the Falcon. This midget missile is only six feet long and weighs in at 100 pounds.

But it was underground where the cause of humanity really was served by control. Anyone who has ridden New York's IRT subway at rush hour will appreciate this: the city's transit authority has awarded a contract to Union Switch and Signal Div. of Westinghouse Air Brake for an automatic traffic control system which "will increase service 25.5 per cent." Crushed Gothamites soon may be amazed to find elbow room—underground.



PEGASUS Linear Servo Actuators

For linear control applications, Pegasus offers industry a series of servo actuators of various capacities.

Ram actuators Model 123, Model 124, and Model 125 provide areas of approximately 1, 2, and 5 square inches, and strokes of 1.5, 4.0 and 4.0 inches respectively. Ram actuators of other areas and strokes are available on special order.

A differential transformer position pickup is mounted concentrically within the hollow ram shaft of each actuator, and manifold mounting is provided to fit any of the standard Pegasus servo valves.

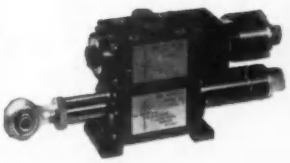
The servo valves Model 120-B (¾" spool), Model 140 (¾" spool), and Model 140-A-120-B (two-stage) provide flow capacities of approximately 5, 10, and 20 G.P.M. at a valve pressure drop of 1000 P.S.I. Spool drive for these valves is through a hydraulic flapper boost from a force motor.

Let us quote on *your* Linear Control problems.

SPECIFICATIONS

MODEL 124-140

Operating Pressure 200 to 3000 psi
Stroke ..... ±2.00 inches
Ram Area ..... 1.975 sq. in.
Velocity (1000 psi valve pressure drop) .. 20 in./sec.
Position repeatability . .002 inches
Natural Frequency (closed loop) ..... 80 cps.

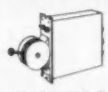


MODEL 123-120-B

Operating Pressure 200 to 3000 psi
Stroke ..... ±.750 inches
Ram Area ..... .895 sq. in.
Velocity (1000 psi valve pressure drop) .. 20 in./sec.
Position Repeatability. .0007 inches
Natural Frequency (closed loop) ..... 80 cps

PEGASUS LABORATORIES, INC. 3690 Eleven Mile Rd., Berkley, Mich.

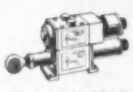
DESIGN AND MANUFACTURE OF ELECTRO-HYDRAULIC SERVOMECHANISMS


Model 117-C Transmitter Amplifier

Model 122-120-B Rotary Actuator

Model 140-120 Two Stage Valve

Model 109-F Force Motor


Model 123-120-B Linear Actuator

Model 108-D Servo Amplifier

An Iron Curtain Switch On Power Conservation

According to "The Press and the Soviet Union", a combination of two switches and a relay will save power-conscious production plants east of the Danube "millions of kwh annually."

The switch-relay combination is designed to shut off power to lathes or drills when the work piece is removed. One two-position switch mounts at the end of the handlebar which operates the clutch between electric motor and working tool. This one severs the power. But between this switch and the motor is a relay which restarts the motor so that it will have sufficient rpm when work again commences. Also, a quick-flipping switch is there to block power to the motor in an emergency.

This invention, of Czech engineers Lindner and Vortuba, might also function as an information input on minutes spent at the samovar by idling lathe operators.

COMPUTER ROUND-UP

Gets Flying Canuks Home

When a jet gets low on fuel it's time to head for the nearest friendly airport. But radio and ground searching for position at supersonic speed can involve some frenzied–and often fatal–minutes. RCAF pilots, aided by a Computing Devices of Canada invention, now can find a safe berth as easily as finding Toronto on a car radio.

The new Position and Homing Computer, tested by RCAF, actually does look like a car radio–augmented by a circular display screen. The pilot selects an airport by pressing one of five push buttons. Two lines then flash on the display. Where they cross indicates the position of the airport. And a needle in the display shows how the plane is heading. The pilot simply banks his plane to point the needle at the crossed lines and zooms neatly into port.

Not too much has been revealed on how this computer works. But it's claimed to be independent of radio and unaffected by atmospheric noise or enemy jamming. And potent enough for some high priority scrutiny by the USAF and RAF.

Computers Wax at Wayne

Wayne University's venerable (3-year old) computer center is due for a new spurt of growth. A brand-new endowment for the Detroit institution's busy facility will provide for more staff, additional analog equipment, and improved memory and input-output features for its Burrough's UDEC.

Besides its many engineering development and research contributions, Wayne's center has done an epic job of supplying computer-trained people to industry. Over 500 students have taken credit courses in computers and their application and some 240 people from commerce have crammed at special Wayne sessions. Last summer 160 neophyte computer operators convened in Detroit to bone up.

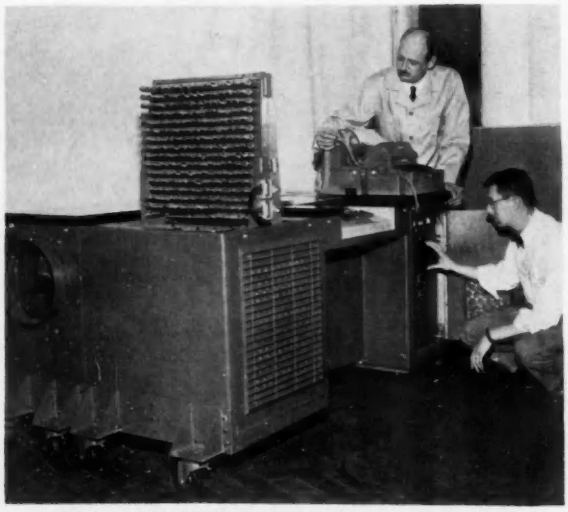
Honeywell, Raytheon Join Digits

Minneapolis-Honeywell Regulator Co. and Raytheon Manufacturing Co. will soon team their considerable know-how in electronics and automatic control to form the jointly owned Datamatic Corporation. The new operation, designed to engineer and market data processing systems, will headquarter in Waltham, Mass., with its own administrative staff. Honeywell will have a 60 per cent and Raytheon a 40 per cent interest in Datamatic.

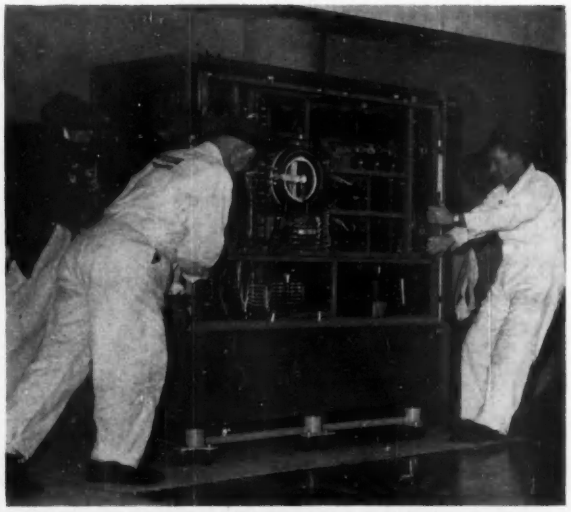
Code Library Coddles Clients

Clients of Midwest Research Institute's active engineering service rarely gripe about their bill these days. Complex analysis and design jobs–while duck soup for the Institute's well-

Continued on Page 22



MOBILE MAPMAKER: Monroe Calculating Machine Co. created this rugged, caster-borne computer for the Army Corps of Engineers. Called Monorobot V, it's designed to analyze terrain trigonometry and tap out map data right in the field.



FIRST 702 TO MONSANTO: The first 702 data processing system outside IBM's own New York office was wheeled into Monsanto Chemical's St. Louis plant last February 25. This power supply regulator for the logic unit weighs 2,961 pounds.

Over the twelve years that Fairchild has been making precision potentiometers — from our first unit (Type 736), on through the more than eighteen different types now in production — we have established and are carrying out a research and development program on new designs and materials, techniques and equipment that is constantly improving our potentiometer reliability. The results of this program are quickly applied to production units and these improved methods and designs are maintained by comprehensive quality control and type testing programs.

MAXIMUM RELIABILITY . . .

how do you get it?

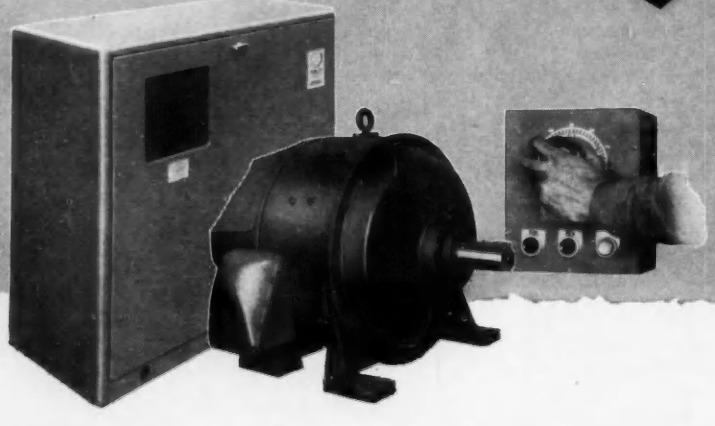
Reliability in precision potentiometers resolves itself into three basic factors; longer shelf life, longer rotational life, and longer environmental life. Fairchild has increased the average shelf and rotational life expectancy of precision potentiometers far beyond usually expected life cycles, in one way, by compounding and using special potentiometer lubricants. Life expectancy and stability under abnormal operating conditions have been vastly increased through the use of precision-machined aluminum alloy case construction. Epoxy resin insulation, one-piece Paliney conductive springs and contacts, and precious metal alloy resistance elements, for certain applications, also contribute to increased life and functional reliability. Whether one or all of these factors of reliability are important to you, you'll do better to choose Fairchild Precision Potentiometers. For specific facts, write Fairchild Camera and Instrument Corporation, Potentiometer Division, 225 Park Avenue, Hicksville, Long Island, New York, Department 140-64C.

FAIRCHILD
PRECISION POTENTIOMETERS

117 Years of VARIABLE

A-C. MOTORS • D-C. MOTORS • GEARMOTORS • ELECTRONIC CONTROLS • REGULATORS • M-G SETS • GENERATORS •

RELIANCE V★S AND DRIVE ®



D-1494

RELIANCE ELECTRIC AND ENGINEERING CO.

CLEVELAND 10, OHIO

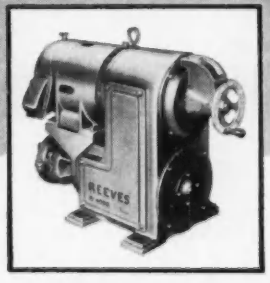
SPEED Drive Experience!

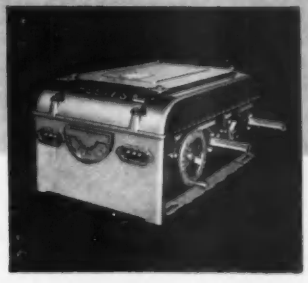
Announcing the combining of the engineering facilities and application experience of two great names in the power transmission field...

REEVES

Vari Speed Drives

VARI-SPEED MOTODRIVE • VARI-SPEED MOTOR PULLEY • FLEXI-SPEED DRIVE • VARIABLE SPEED TRANSMISSION





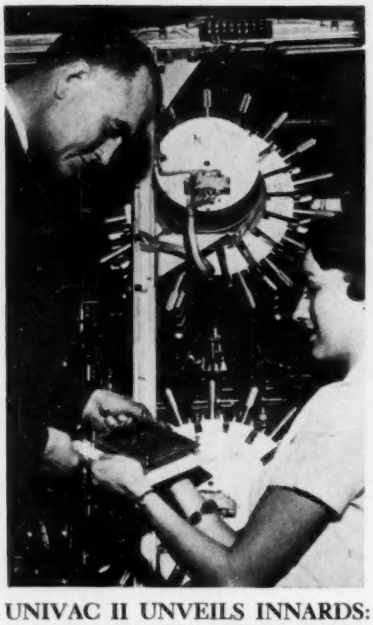
REEVES PULLEY COMPANY

COLUMBUS, INDIANA

DIVISION OF

RELIANCE ELECTRIC AND ENGINEERING CO.

equipped computer laboratory — involved some costly technical man-hours in pre-computer programming. Midwest has now gotten around this by setting up a code library which contains computer instructions for a wide range of mechanical, electrical, chemical, and civil engineering problems. The client is only docked for the short time required to select and set-up the coded instructions plus a nominal per cent which is put toward further development of the code library.



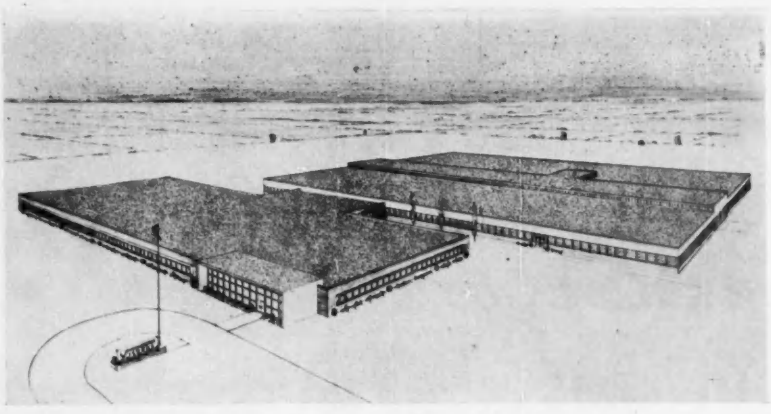
UNIVAC II UNVEILS INNARDS: Remington Rand Vice President John E. Parker and a comely assistant are looking at the new magnetic core matrix which is responsible for doubling the speed and capacity of the company's famous Univac. Background is the magnetic memory tank which the tiny core replaces.

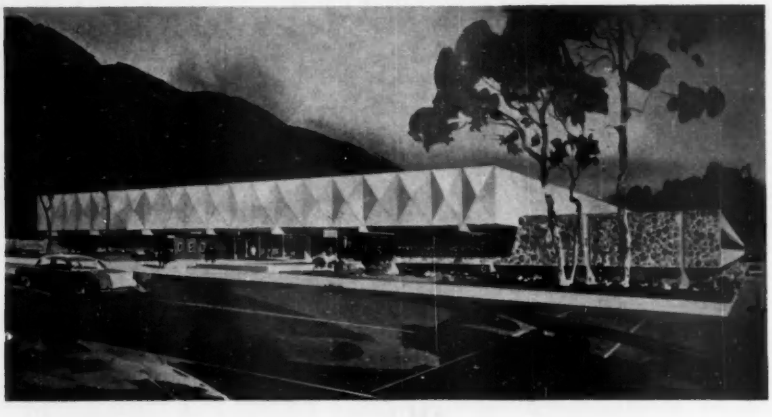
If the Shoe Fits—Record It

In the near future the purchase of a pair of B. F. Goodrich shoes will end up on a magnetic storage drum—and another pair will be sped to the outlet to be worn by the next customer who likes that style.

The prime mover behind this scheme is a new Teleregister electronic inventory control system in the Goodrich Watertown, Mass., plant. All styles and sizes on hand will reel off and on the drum as stock is produced

Continued on page 24





Control Complete With Palms and Pedestrians

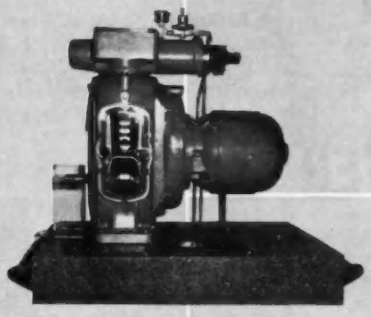
These plants, in descending order, are projects of Vickers, Inc., Consolidated Engineering Corp., and Electronic Specialty Co. Contrast the bold accoutrements with which California architects embellish their sketches with the stark, strictly functional layout of the Vickers plan. This, an engineering and administration building to be built in suburban Detroit, will include a research and development lab in its 150,000 sq ft. The second, to embrace 120,000 sq ft in Pasadena, will house CEC's Research Engineering and Marketing Divs. The third, in Los Angeles, includes all divisions of Electronic Specialty in its 20,000 sq ft.

CONOFLOW *Cylinder Conomotors*
now make possible a *complete selection* of
FINAL CONTROL ELEMENTS

Conoflow Series LB Control Valve

CONVENTIONAL—Control Valve

One of the most conventional methods of controlling practically any variable is to use a control valve to regulate the fluid stream on the discharge side of a pump or similar prime mover. This is, of course, a simple and obvious approach, but frequently poses serious problems especially when handling extremely viscous materials, abrasive materials, corrosive fluids, etc. One of the proved and accepted methods of hurdling these perplexing obstacles is to control at the source by positioning .....



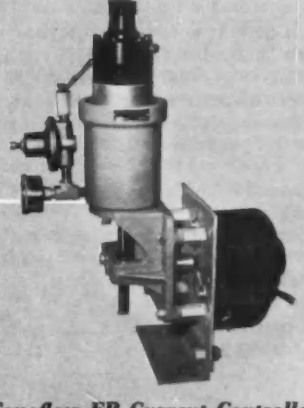
Cylinder Conomotor actuating variable speed drive (Link Belt)

.....THE PRIME MOVER—*mechanically*

In this manner the prime mover is actuated directly by the control instrument—eliminating the necessity of breaking into the line downstream to install a control valve. A most common method of accomplishing this is to control the pump speed by means of a mechanical variable speed transmission. Cylinder Conomotors are available as original equipment on a wide variety of drive units similar to the one illustrated here, including U. S. Electrical Motors, Sterling Electric Motors, Graham Transmissions, Reeves Pulley, etc. Many pumps have been adapted for direct control by using Cylinder Conomotors to automatically adjust pump stroke as in the Lapp Pulsafeeder and Milton Roy pumps. In some cases it is more practical to control at the source through electrical means by modulating .....

.....THE PRIME MOVER—*electrically*

Conoflow EB Current Controllers operating from a 3-15 or other standard range pneumatic controller are available in over 200 combinations of electrical components for controlling voltage, current, inductance, capacitance, resistance or other electrical values. A common approach to the regulation of fluid flow in this manner is to position the rheostat in the motor field or the armature circuit as a direct function of signal pressure, thereby regulating the speed of the D.C. shunt-wound motor driving the pump. On many applications, variable speed transmissions and electric motors can be controlled from zero to full capacity offering a resultant control range that cannot be matched by conventional control valves. In installations involving large capacity equipment this can prove extremely important since it eliminates the needless operation of large centrifugal pumps running at constant speed wasting power by discharging against a stalled or greatly restricted head.



Conoflow EB Current Controller positioning rheostat

For additional information on Conoflow Cylinder Operators write for Bulletin B-50-2.

CC 900

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Bendix G-15

GENERAL PURPOSE COMPUTER

Check these facts...

✓ **UTILITY** A stored program digital computer for the solution of the lengthy and complex mathematical problems encountered in industry and research. The G-15 performs all arithmetic and logical operations with unusual versatility.

✓ **FLEXIBILITY** An electric typewriter, photo-electric tape reader and a tape punch unit are furnished as standard input/output equipment. Accessories such as magnetic tape units, graph plotters and coupling units to permit use of punch cards are available.

✓ **CONVENIENCE** Because the G-15 occupies only as much space as two standard filing cabinets, special facilities are not required for installation. The unit is mounted on casters and can easily be relocated. Input/output equipment can be installed adjacent to the computer cabinet or at a remote location.

✓ **QUALITY** Designed and manufactured by Bendix Aviation Corporation, builders of the world's finest electronic equipment. Every major airline and the Armed Forces depend upon Bendix equipment for communications and navigation where reliability and accuracy are paramount. The same standard of quality is built into Bendix Computers.

✓ **AVAILABILITY** The G-15 is in quantity production which assures you of prompt delivery.

✓ **ECONOMY** Initial cost is the lowest of any comparable computer. Maintenance cost is lowest because of rugged built-in quality and plug-in construction.

Bendix Computer

Bendix Computer Division
5630 Arbor Vitae Street • Los Angeles 45, Calif.
Please send information and prices on your G-15 Computers.

Name_____
Title_____
Company_____
Address_____

EXPORT DIVISION: BENDIX INTERNATIONAL, 205 EAST 42nd STREET, NEW YORK, N.Y.

WHAT'S NEW

and used. The system involves a continuous tabulated summary which will guide production and fill warehouses and store shelves almost as fast as they are emptied. Input data will come from a keyset in the warehouse and Flexowriter in the sales office. Actual flow of stock will be followed on the computer-actuated Inventory Display Board.

Important Moves by Key People

► **William M. Pease,** formerly director of the Servomechanisms Laboratory at M.I.T., and more recently manager of the Electronics Div. of Ultrasonic Corp., has been appointed vice-president and general manager of Feedback Controls, Inc.

► **Robert E. Navin** will concentrate on engineering activities of The Hays Corp. as its new assistant to the executive vice-president. He has been with Detroit Bevel Gear Co. for six years.

Navin named engineer-executive of Hays.

► Ampex Corp. has appointed **John V. Zuckerman** manager of personnel and plant services and **James I. Stultz** head of a new Customer Relations Dept. Zuckerman will be assisted by **Robert I. Cooper,** supervisor of personnel relations; **A. J. Wilson, Jr.,** plant engineer, and **Harold E. Kren,** head of the Office Services Dept. Stultz has managed the Field Service Engineering Dept. since 1952.

► Reliance Electric & Engineering Co.'s recent acquisition of Reeves Pulley Co. has prompted these changes: appointment of **Richard A. Geuder** as assistant general sales manager; assign-

Illustration actual size

Weight — 11 ounces

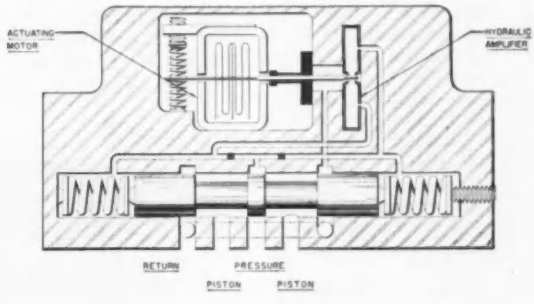
On 67% Of Bombardment Missile Programs
On 50% Of Fighter Aircraft Programs

Many thousands of Moog Servo Valves are now in use in exacting applications on advanced aircraft and guided missiles. This widespread usage attests to Moog features of reliability and high performance which have gained for these units recognition as the industry standard.

Now, these same features may be obtained in Moog's new Dry Solenoid Servo Valves. These units, illustrated above by Model 2000, feature a torque motor that is isolated from contact with the hydraulic fluid. The Dry Solenoids have been developed for those systems in which the fluid might otherwise contaminate the torque motor. They are even smaller and lighter than other Moog units of the same flow capacity and comply with requirements of MIL-H-5440A.

Moog Servo Valves are proportional type, electrically actuated, hydraulic, four-way valves featuring high dynamic response, sensitivity, linearity, small size and low weight. Production models are designed to operate in hydraulic systems of from 1000 to 3000 PSI pressure. Rated output flows from 0.1 to 50.0 GPM for control currents between 2.0 and 40.0 milliamperes as specified are available in production units.

Conventionally, valve input is from a balanced push-pull DC amplifier and valve flow output is applied to a piston or hydraulic motor. An electric signal proportional to piston position or motor angular rotation is fed back to the amplifier to give a closed servo loop.



For details write for Bulletin 2000-2

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solves
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3-5/8" high by
2-5/8" deep.
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TIMETER automatically records operating time of electrically operated equipment; furnishes accurate records for time study, cost analyses; checks test runs, lamp and tube life; ferrets out lost man- and machine-hours. Operates independent of load. Rating: 100-125 volts, 60 cycles, 2 watts, A.C. Transformer or resistor supplied for higher voltage. Registers by 10ths of hours or minutes to 999.9 then repeats. Available up to 99,999.9 hours or minutes. Re-set feature optional. Write for data, prices.

TYPICAL APPLICATIONS

- Light & Power Circuits
- Industrial Equipment
- Leased Machinery
- Motor Driven Stokers
- Presses
- Machine Tools
- Generators
- All types of production machinery
- Elevators

CAPEWAY INSTRUMENT CORP.

HIGHLAND AVENUE PLANT

EAST BRIDGEWATER, MASS.

WHAT'S NEW

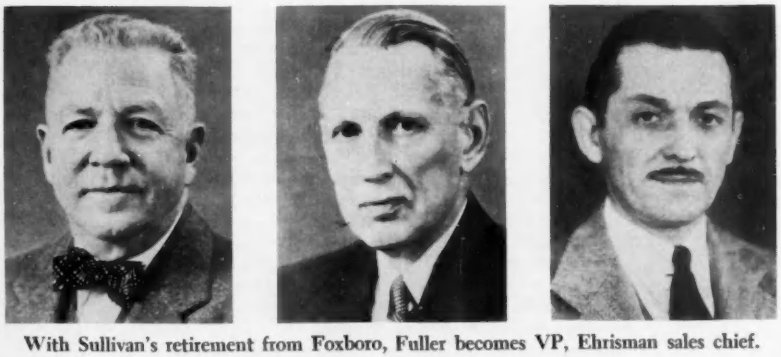
ment of **Edward E. Helm**, sales vice-president, as coordinator of the merger, and transfer of **Frank B. Carr** to Reeves as resident coordinator. The three men joined Reliance in 1924, 1929, and 1952, respectively.

Walters to key factory position at Taylor.

► **William M. Walters** has been promoted from division superintendent to general factory superintendent of Taylor Instrument Cos., succeeding the late **Donald C. Lamb.** He joined Taylor in 1936 and was named to his most recent position in the Industrial Instrument Assembly Depts. in 1949.

► **C. E. Sullivan**, general sales manager of The Foxboro Co., and a well known figure in automatic control, has retired. At the same time the company made these top-draw appointments in its sales department: **C. C. Fuller** to vice-president, **H. O. Ehrisman** to general sales manager and **J. J. Burnett** to field sales manager. Sullivan, who will continue as a consultant, joined the company in 1908 when it was Standard Gauge Mfg. Co. Fuller, who will head a new sales product development committee, has been with Foxboro since 1920. Ehrisman, chairman of a new sales policy committee to coordinate sales engineering and manufacturing, joined in 1936. He has specialized in control instrumentation for the paper industry. Burnett, who will supervise Foxboro's 48 branch offices in the U. S., began with the company in 1925.

► **Edmund D. Gittens** has been promoted to vice-president and chief engineer in the Arma Div. of American Bosch Arma Corp. Also promoted in the division: **Clifton T. Foss** to vice-president and general manager and **Clarence H. Hopper** to vice-president-manufacturing. Gittens, with Arma for 20 years, has been chief engineer since 1951. Foss's service embraces 21 years. He became vice-president-



With Sullivan's retirement from Foxboro, Fuller becomes VP, Ehrisman sales chief.

Arma VPs: Gittens, chief engineer, Foss, general manager, Hopper, manufacturing.

VARITROL® automatic variable speed

SAVES MANPOWER

IMPROVES PRODUCT

INCREASES OUTPUT

Now, by controlling speed with the Varitrol as a component of the U. S. Varidrive motor, speeds can be *automatically* changed in response to a signal *without* human attention for precision-control operations. At right is shown just one of the many ways in which Varitrol automatic control of U. S. Varidrive motors can be used for automatic production control. An educational booklet, edited by variable speed engineers, illustrates with applications this method of greater production of more goods and services at lower cost and astounding man-hour savings. Write today for your complimentary copy.

SYNCHRONIZATION

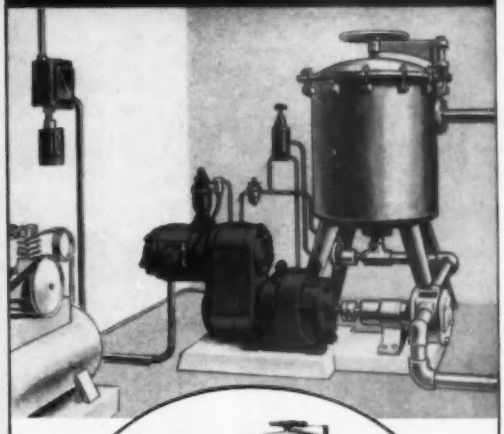
CONSTANT VELOCITY

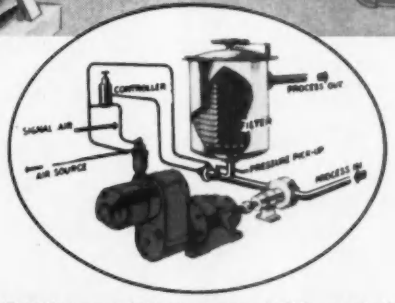
WEIGHT CONTROL

HUMIDITY CONTROL

HEAT CONTROL

PRESSURE CONTROL





A Varidrive-operated pump runs at high speed with clean filter to obtain maximum flow. As filter clogs, pressure pick-up signals Varidrive which gradually slows down to limit filter back-pressure. When filter is clean, speed automatically increases.

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Do you think about Angular Acceleration?

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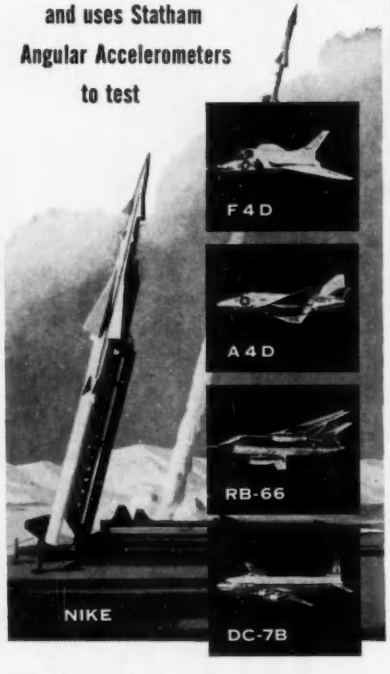
and uses Statham Angular Accelerometers to test



Statham unbonded strain gage liquid rotor angular accelerometers offer a simple, reliable means for the study of the rotary motion of a test body under conditions where a fixed mechanical reference is not available. For static and dynamic measurements in ranges from ±1.5 to ±3,000 rad/sec², four standard models are offered.

Please request Bulletin AA2

Statham

LABORATORIES

LOS ANGELES 64, CALIFORNIA

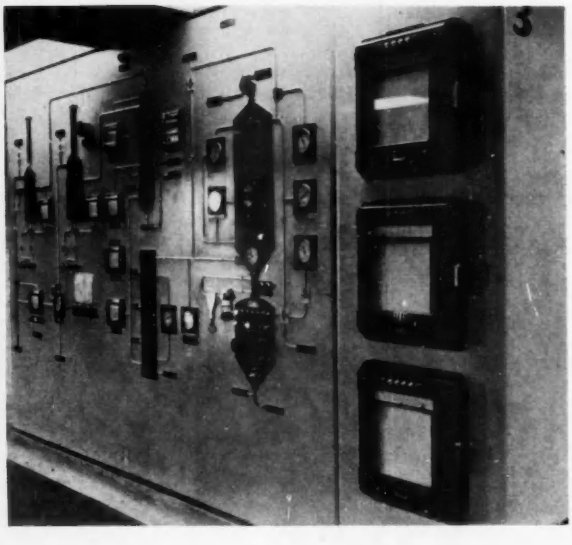
WHAT'S NEW

engineering in 1950 and that plus assistant general manager in 1954. Hopper, works manager since 1954, was with ACF-Brill Motors Co. for 19 years. **Kenneth F. Leaman** was promoted to vice-president-manufacturing in the American Bosch Div. of the corporation.

▶ **Perry R. Roehm,** a new vice-president of Norden-Ketay, will coordinate sales and product engineering. He comes to Norden-Ketay from The Barden Corp., where he has been vice-president and director. He also served as chief production engineer of Carl L. Norden, Inc., and production superintendent of the Navy bombsight facility at Elmira, N. Y.

▶ **Sumner Ladd,** factory sales engineer of General Controls Co. since 1953, has been named manager of the Industrial Controls Div.

Ladd pilots General Controls Division.



Graphic control panel for the acetylene process at American Cyanamid's new Fortier, La. plant is first to integrate in-stream infrared analyzers. Top and bottom recorders indicate acetylene and methane concentrations.

In-Stream Analyzers Spark Unique Acetylene Process

At war's end, American Cyanamid chemists latched on to I. G. Farben's efficient but explosive process for making acetylene by burning oxygen with natural gas. But pilot plant studies convinced them that some drastic control innovations would be necessary for commercial production. Routine laboratory purity analyses, particularly, would have been too costly and, in view of the time delay, dangerously late for this critical process.

The bold results of Cyanamid thinking can now be seen in the company's sprawling new $50-million petrochemical plant in Fortier, La.

At Fortier, the purity of gas going to the acetylene unit is continuously monitored by two in-stream Perkin-Elmer infrared analyzers (see cut). The process operator studies these instruments to set the exact ratio of methane to oxygen to the burners. This complicated routine—a function of gas purity, flow, and by-product requirements—is now being dynamically analyzed with an eye to use of a computer and feedback control.

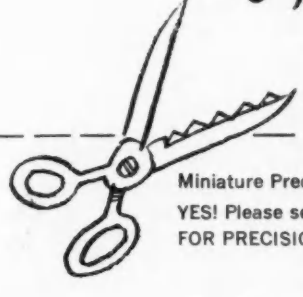
Taking cue from the acetylene unit, several other in-stream analyzers are used at Fortier. One measures acetylene concentration to the compressors. Another, at the absorbing column, spots off gas down to 0.3 per cent. Two more, at purifying towers, measure carbon monoxide concentration. Still another picks up any poisonous

Ready for the Rope?

Don't give up! Here's all you need in order to get the whole story of how these MPB's*

BALL BEARINGS ACTUAL SIZE

are solving problems in the design of precision instruments



CUT THE CALAMITY AND CUT OUT THE COUPON

Miniature Precision Bearings, Inc., 9 Precision Park, Keene, N. H.
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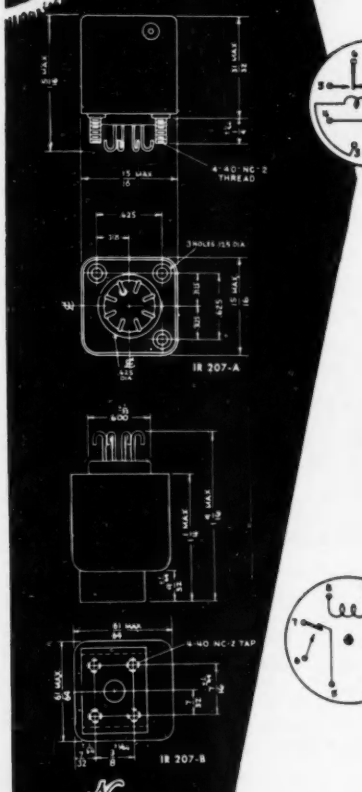
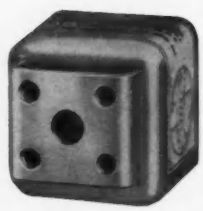
ROTARY ARMATURE

IR 207 RELAYS by NORTH

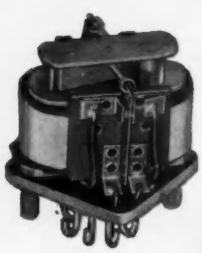
A subminiature rotary armature relay designed for a variety of airborne and guided missile applications where *reliable* operation in severe environment is required.

1. Two form C contacts rated at 2 amps, 30 volts, DC resistive.
2. Low capacity between contacts and ground.
3. The standard IR 207 relay meets the reliability requirements under MIL-R-5757B.
4. For critical applications where more reliability is required than is provided under MIL-R-5757B, North's "Special *High* Reliability" hermetically *sealed* relays are now available.





IR 207-B Bracket Type mounting equipped with 4 holes for 4-40 screws



Standard IR 207-Relay: Internal Structure

IR 207-C Type with standard octal plug base

Detailed specifications available on request.

THE NORTH ELECTRIC MANUFACTURING COMPANY

Originators of ALL RELAY Systems of Automatic Switching

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WHAT'S NEW

oxygen compound traces at the ammonia unit. And two infrared analyzers scout carbon gas traces at the caustic soda scrubbers.

While only one in-stream analyzer now has a control role (reflux rate in purifying tower), many of these operations may be handled automatically in the near future.

MIT Lines Up Program In Numerical Control

Machining by numerical control will be studied, observed, and applied at a special program for working engineers at MIT this summer. The Aug. 22-Sept. 2 sessions will be piloted by Prof. J. Francis Reintjes, director of the Servomechanisms Laboratory, with the cooperation of James O. McDonough and other members of the numerical control group in the lab.

Lecture topics will include principles of information-processing with an eye to machine tools, numerical control systems and their machine tool applications, equipment design, designing for reliability, and management, operation, and maintenance of the tools. Sessions devoted to programming techniques will cover mathematics of programming, practical procedures, and machine aids.

AROUND THE BUSINESS LOOP

Henry F. Dever Is New SAMA President

Henry F. Dever, President of Minneapolis-Honeywell's Brown Instruments Div., was elected President of Scientific Apparatus Makers Association at its recent annual meeting in White Sulphur Springs, W. Va. Among other 1955-56 officers: R. E. Welch of W. M. Welch Mfg. Co., President Pro Tempore; T. M. Mints of E. H. Sargent & Co., Treasurer, and B. N. Bristol, President of The Foxboro Co., recorder-controller.

► **Sunshine Scientific Instrument** has acquired from **General Electric Co.** the right to manufacture, sell, and service 18 testing and measuring instruments originally designed by GE's Special Products Div. Sunshine Catalog 101 describes the instruments.

► At about the same time **Consolidated Engineering Corp.** acquired similar rights to four plant analysis and control instruments developed by

Four minutes to carrier deck... three...two... home again! At supersonic speeds fuel reserves must be measured in minutes and seconds of flying time — not hours. And in jet aircraft that's the job of the automatic fuel flow totalizer. Into these instruments go **SYNCHROS** which transmit data accurately to the cockpit.

Because of their vital role, the Air Force demands synchros of the highest precision... and Norden-Ketay supplies them.

VITAL TO JET AIRCRAFT

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...IN CHEMICAL PLANTS, TOO

Industry, too, is using **SYNCHROS**. For example, the chemical, food, and petroleum processing industries use **SYNCHROS** in remote control applications to reduce operating costs and assure uniformity in their products.

Look to Norden-Ketay for

SYNCHROS • SERVO MOTORS • DIGITAL CONVERTERS
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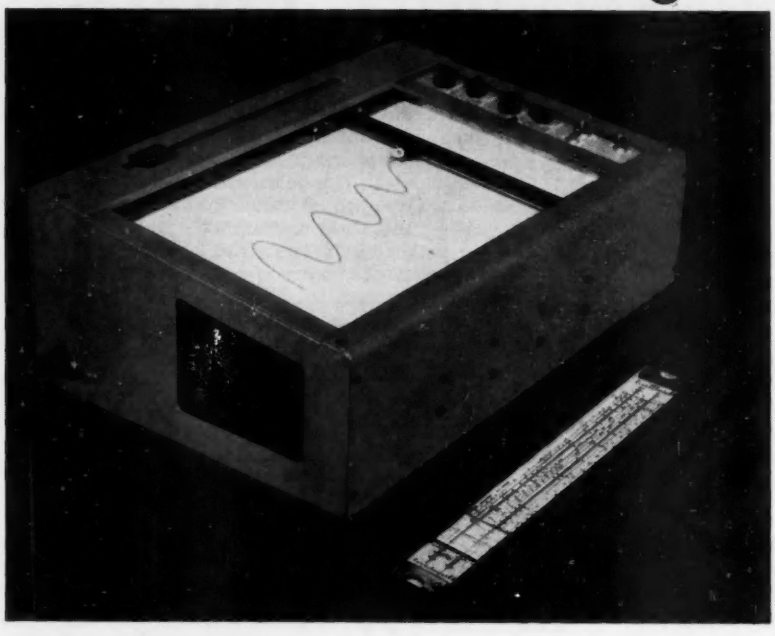
The Norden Laboratories, White Plains, N. Y.

MANUFACTURING DIVISIONS:
Precision Components Division, New York, N. Y.
Commack, Long Island, N. Y., Hawthorne, California

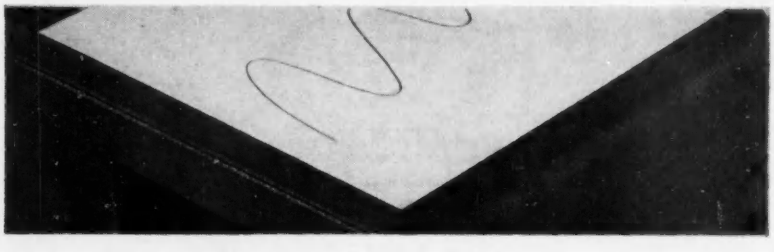
Instrument and Systems Division: Milford, Connecticut

SUBSIDIARIES: Nuclear Science and Engineering Corporation, Pittsburgh, Penn.
Vari-ohm Corp., Amityville, Long Island, N. Y.

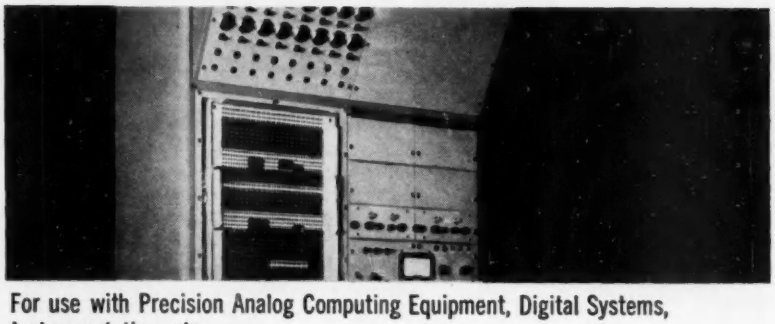
News in X-Y Recording



The new Variplotter Model 1100 Plotting Board



Including vacuum hold-down for plotting paper, finer accuracy, faster response



For use with Precision Analog Computing Equipment, Digital Systems, Instrumentation, etc.

Variplotter Model 1100 – Provides rapid (pen slews at approximately 20" per second) graphic recording of any data that can be reduced to electrical form. Same reliable accuracy as the well-known 205 series Variplotter. Ideal where compactness is essential without loss of speed or performance. Designed for use in recording computer outputs (as with EAI 16-31R pictured above), generating functions, or with additional equipment – for plotting digital information from punch cards or tape. For complete brochure write Department CE-8 Electronic Associates, Inc., Long Branch, New Jersey.

ELECTRONIC ASSOCIATES Incorporated — EAI SETS THE P PRECISION A ANALOG C COMPUTING E EQUIPMENT

LONG BRANCH, NEW JERSEY

WHAT'S NEW

Phillips Petroleum Co. for petroleum and petrochemical processes. Marketing under the Consolidated label probably will start this summer.

▶ **Askania Regulator Co.**, which has taken over **Heniz Engineering Co.**, will carry forward Heinz' work in system engineering. Winfield B. Heinz joins Askania as chief engineer in the Industrial and Special Devices Divs.

▶ **CDC Control Services** has appointed a sales representative in France, French North Africa, West Germany, Italy, Luxembourg, Belgium, and the Netherlands. The firm is Exploitation de Produits Industriels of Paris.

▶ With the acquisition by **Texas Instruments, Inc.** of **Radell Corp.**, Radell's deposited carbon precision resistors join the products of TI's Components Div. John R. Pies, formerly manager of Radell, becomes chief engineer.

▶ **Helipot Corp.** will consolidate in a $2 million plant in Newport Beach, Calif., its manufacturing and administrative facilities now located in various California cities. The California payroll is expected to increase from 600 to more than 1,000 when the plant is completed. Expected time: mid-1956. Plants in Mountainside, N. J., and Toronto also are expanding.

▶ Helipot's "parent" corporation, **Beckman Instruments, Inc.**, is in the news in its own right. Its Fullerton, Calif., plant was named by "Factory Management and Maintenance" as one of the ten most significant manufacturing plants built in the U. S. in 1954. The Fullerton building was one of 500 submitted for judgment.

▶ The home of **Sperry Corp.**'s Electronic Tube Div., designed for production of klystron and traveling wave tubes, has been completed in Gainesville, Fla. Installation of $2 million worth of machinery in the $900,000 plant is under way and output is expected to reach its peak by the spring of 1956.

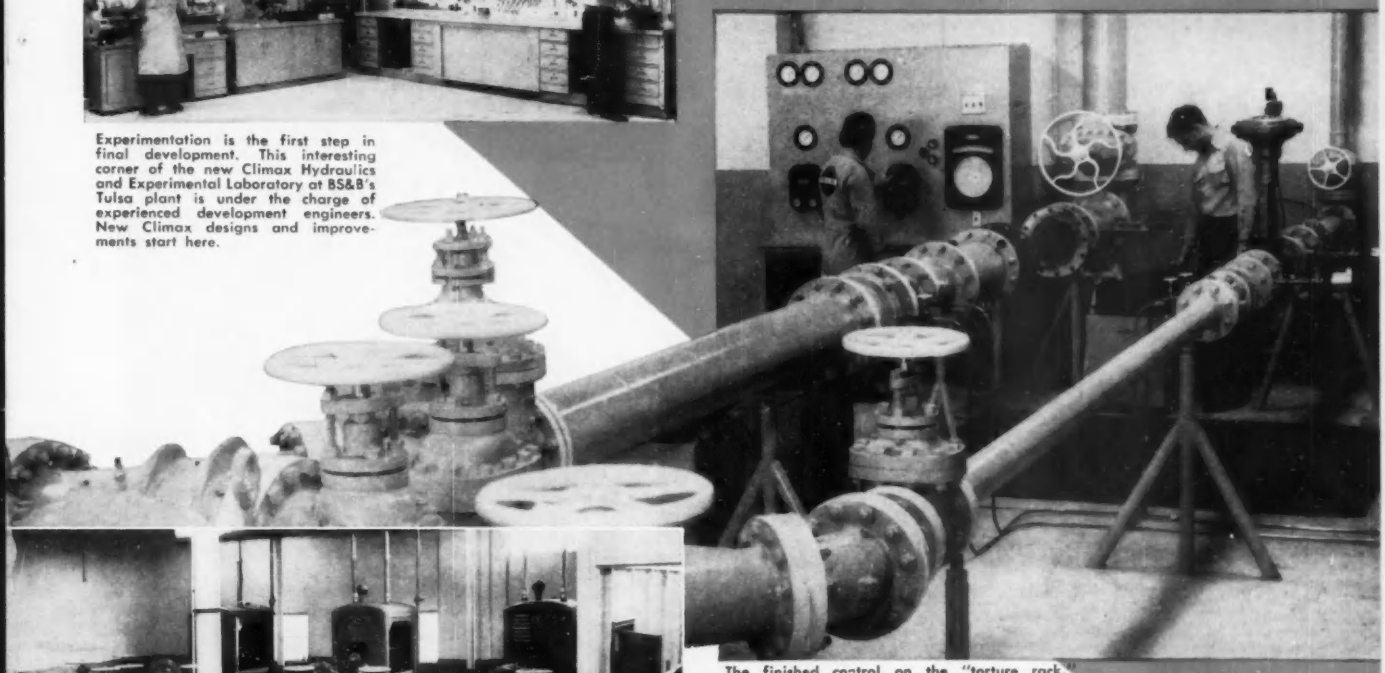
▶ All the voting stock of **Freed Electronics & Control Corp.** now is in the hands of **Fairchild Camera & Instrument Corp.** Freed, as a subsidiary of Fairchild, will retain its separate identity, its officers and its personnel. J. A. Hewlett and C. L. Terrill, treasurer and vice-president, respectively, of Fairchild, become treasurer and secretary, respectively, of Freed.

▶ The tide of acquisitions is running heavy. In another, **Mag-Electric Products, Inc.**, has taken over **Mag-Electric Network, Inc.** All engineering and production personnel have been retained.

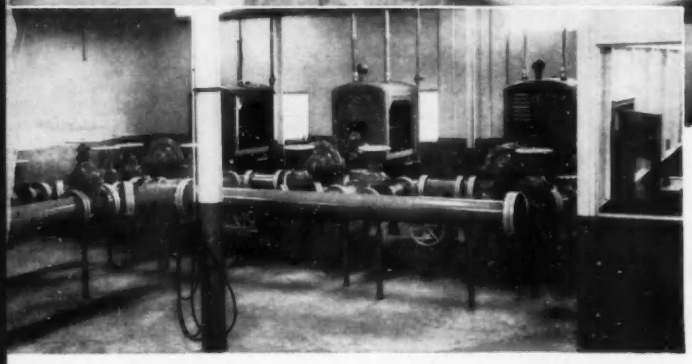
Testing the performance on which BS&B reputation has been built;

Pre-Proving CLIMAX CONTROLS to Insure On-The-Job Efficiency

Experimentation is the first step in final development. This interesting corner of the new Climax Hydraulics and Experimental Laboratory at BS&B's Tulsa plant is under the charge of experienced development engineers. New Climax designs and improvements start here.



The finished control on the "torture rack." Meter runs flow test the valves up through 10". Strain gauge equipment analyzes forces and stress under performance. Control panel in background regulates engines driving the pumps and registers flow data for calculation.



Pump manifolding for the 3 engine-driven pumps which will deliver up to 4500 gallons per minute at a 100 lb. discharge for high volume tests. Pumps can also be manifolded for series operation, in which case 1500 gallons of water at 300 lbs. pressure can be delivered per minute.

There's no question about a Climax Control giving the satisfactory service for which it is designed. That performance is tested and proven before the control goes into the field . . . checked for minimum and maximum capacity. Flow, flow effects, valve characteristics and strain results are all evaluated by experienced engineers. Through the new BS&B Climax Control Hydraulics laboratory come a continuing series of answers to the more efficient, safe and profitable application of automatic controls. One test suggests another, one application is adapted to a similar problem. The net result: Through research, better engineering, and accurate pre-testing, comes a more efficient Climax Control.

Climax Controls Hydraulic and Experimental Laboratory

BLACK, SIVALLS & BRYSON, INC.

Climax Controls Division, Dept. 4-ES6
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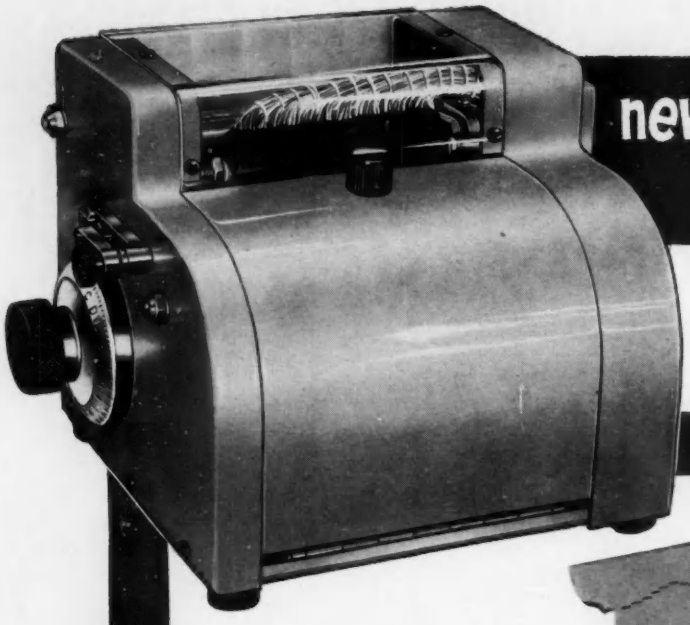
CLIMAX BS&B CONTROLS OUR 60TH YEAR

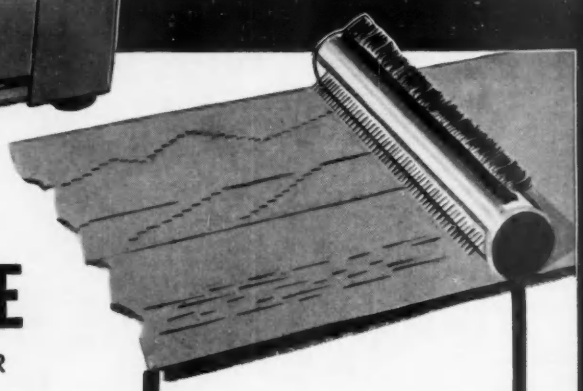


new MINI-SLEUTH

(MINIATURE RECORDER R1021-1)

A PORTABLE laboratory type recorder which allows immediate visual analysis of data.

WEIGHS ONLY 15 lbs.— Light, compact, portable — Dimensions: 9½"x7½"x 8"



212-styli recording head is unaffected by vibration and shock. 5-inch electro-sensitive paper chart provides direct writing on a dry, permanent record. Visible writing without ink or moving writing elements. Chart speed variable from ¼" to 5" per second.

INEXPENSIVE

MONITORING SYSTEM FOR

ON/OFF SEQUENTIAL RECORDINGS

The **MINI-SLEUTH** with its 212 writing styli is a new concept in instrumentation technique . . . a mighty mite of versatility, flexibility and ease of application.

The **MINI-SLEUTH** is a simple means of performing the heretofore complex problems of digital, analog and sequential data recording. It further offers expedient data reduction capability being performed during the recording process by visual or automatic techniques.

Radiation, Inc. fixed multi-style recording systems, featuring large data handling capabilities, help to economically simplify the solutions to instrumentation problems in Aircraft, Missile, Chemical, Mining, Petroleum and other industries. We invite you to submit your inquiries and application problems.

WRITE FOR FULL DETAILS

WRITE FOR CHARTS OF TYPICAL APPLICATIONS:

(1) Automatic Sequence Operation Monitor
(2) Production Sequence Time Monitor
(3) Automatic Cable Tester
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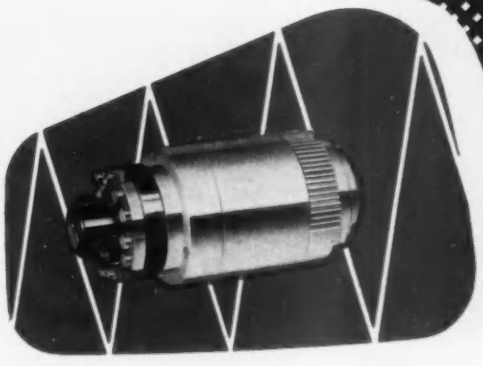

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One of a series telling
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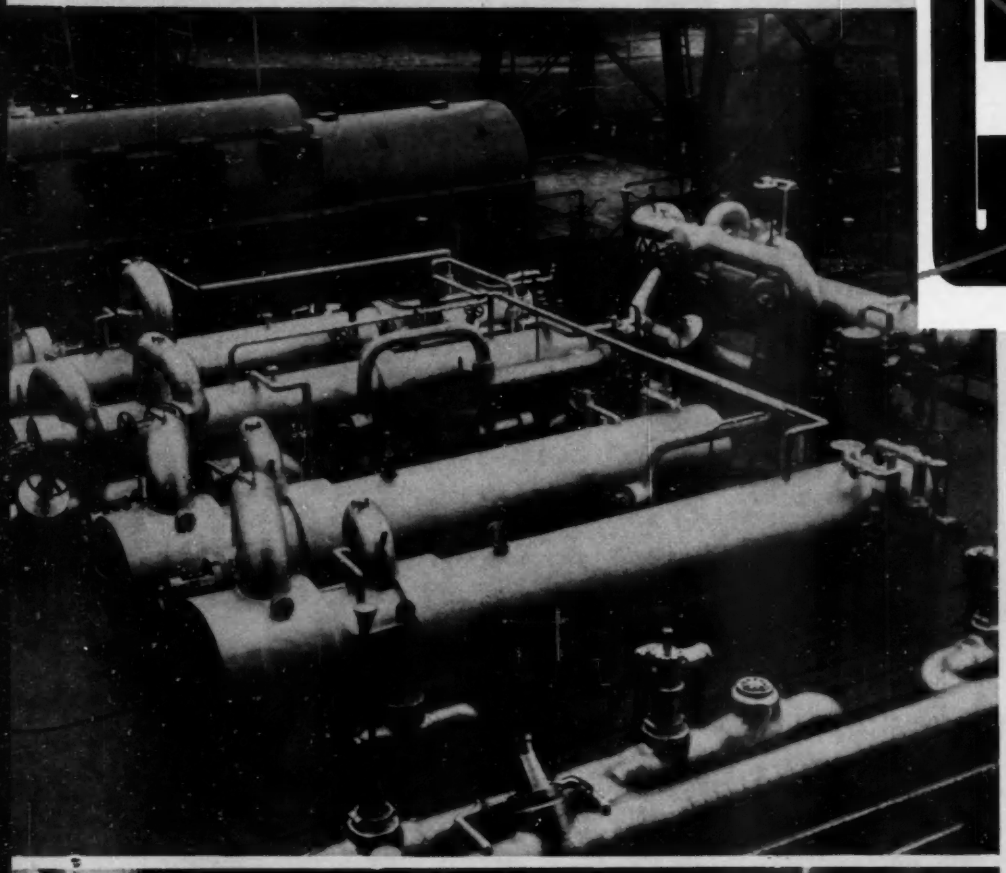
are contributing to America's progress.

GPE.....



Griscom-Russell feed water heaters in a 125,000 KW public-utility power station; save nearly 100 tons of coal per day. Heaters handle flow of water exceeding 2000 G.P.M. at 2500 pounds pressure and steam extracted from the turbine at five different points; "train" of five units pre-heats water fed to boilers from 90° F. to 441° F.

Askania multiple fuel boiler control panel in large steel plant; maintains metered proportion between combustion air and fuels—coke oven gas and fuel oil—for most economical combustion; holds steam pressure constant through all load changes and keeps furnace pressure at a safe and predetermined value.

General Precision Laboratory's Industrial TV Camera, the "Bullet"; portable, easily operated; used to monitor and improve manufacturing processes and to view hazardous industrial operations.

The highly advanced technological products designed and manufactured by the eighteen producing companies of General Precision Equipment Corporation serve more than a dozen major industries. Products of six of these GPE Companies—Griscom-Russell, Askania, Librascope, Link, Kearfott and General Precision Laboratory—have widespread application in the processing and power industries.

Industrial Processing...and Power

The Griscom-Russell Company is one of the country's largest producers in the fields of heat exchange and water distillation. It is the pioneer in heat exchanger equipment—the key to the whole complex of modern industrial processing and power. For over seventy years, G-R equipment has been responsible for greatly increased efficiency and lowered operating costs in industry.

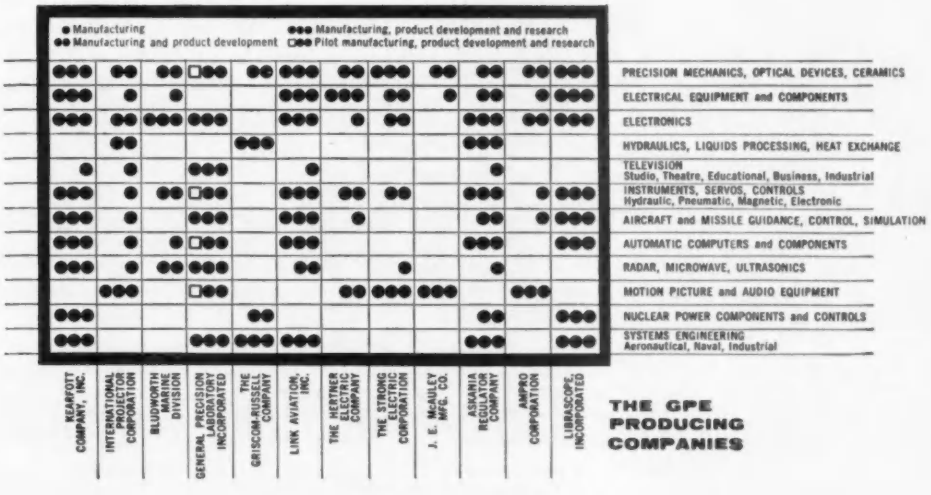
Askania Regulator Company for a quarter of a century has been a leading developer in the field of regulators and controls, including components and systems. Its products are widely used by the power, steel, gas and coke, mining, chemical, petroleum, glass and paper industries—wherever great reliability and accuracy are essential.

Kearfott Company, Inc.; Librascope, Incorporated; and Link Aviation, Inc. produce a wide variety of precision instruments, computers, servos and other control components for equipment and systems used throughout the power and the processing industries. Industrial television equipment manufactured by General Precision Laboratory Incorporated, the sixth GPE Company active in these fields, is playing increasingly important roles in "seeing eye" monitoring operations in these industries.

Each company in the GPE Group works in specific, highly specialized technical areas, as indicated in the chart below. Each of these companies, in addition to specializing in its particular products and fields of technical competence, has at its command, as required, the facilities and specialized techniques of the other GPE Companies in their respective fields. Interrelation is achieved through GPE's basic operating policy, Coordinated Precision Technology.

In the fields of research and development, GPE Coordinated Precision Technology permits a high degree of specialization in particular areas of competence and supplements such specialization by the application of techniques in other fields, as desirable. In the field of production, it makes possible a highly flexible application of facilities. This policy has been responsible for a diversified line of precision equipment of superior design and performance, covering a wide range of both standard and special uses.

Perhaps the most conspicuous advantage of GPE Coordinated Precision Technology is that the concept and development of equipment, and of solutions to the underlying technical problems, are not restricted or distorted by traditional allegiance to specialization in a particular field. GPE coordination permits the engineers and technical personnel of each GPE Company to seek the optimum solution for the customer within the total capacities of the GPE Companies as a group.



A brochure relative to GPE Coordinated Precision Technology and the work of the GPE Companies is available. Address your request, or inquiries on specific problems, to:

General Precision Equipment Corporation

92 GOLD STREET, NEW YORK 38, NEW YORK

Systems Development and The Ramo-Wooldridge Corporation

The Ramo-Wooldridge Corporation (except for the specialized activities of our subsidiary, Pacific Semiconductors, Incorporated) is engaged primarily in developing—and will soon start to manufacture—systems rather than components. For military customers our weapons systems responsibilities are in the fields of guided missiles, fire control, communications, and computers. Our non-military systems activities are in the general area of automation and data-processing.

Emphasis on systems development has consequences that profoundly affect all aspects of an organization. First, it demands an unusual variety of scientific and engineering talent. A single systems development project often requires concurrent solutions of challenging problems in the fields of electronics, aerodynamics, propulsion, random phenomena, structures, and analytic mechanics. In addition, the purely technical aspects of a systems problem are often associated with equally important non-technical problems of operational, tactical, or human relations character.

Therefore, competent systems development requires that a company contain an unusually large proportion of mature, experienced scientists and engineers who have a wide range of technical understanding and an unusual breadth of judgment. Further, all aspects of company operations must be designed so as to maximize the effectiveness of these key men, not only in the conduct of development work but in the choice of projects as well.

At Ramo-Wooldridge we are engaged in building such a company. Today our staff of professional scientists and engineers comprises 40% of the entire organization. Of these men, 40% possess Ph.D. degrees and another 30% possess M.S. degrees. The average experience of this group, past the B.S. degree, is more than eleven years.

We believe the continuing rapid growth of our professional staff is due, in part, to the desire of scientists and engineers to associate with a large group of their contemporaries possessing a wide variety of specialties and backgrounds. It is also an indication that such professional men feel that the Ramo-Wooldridge approach to systems development is an appropriate one.

We plan to continue to maintain the environmental and organizational conditions that scientists and engineers find conducive to effective systems development. It is on these factors that we base our expectation of considerable further company growth.

POSITIONS ARE AVAILABLE FOR SCIENTISTS AND ENGINEERS IN THESE FIELDS OF CURRENT ACTIVITY:

Guided Missile Research and Development
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The Ramo-Wooldridge Corporation

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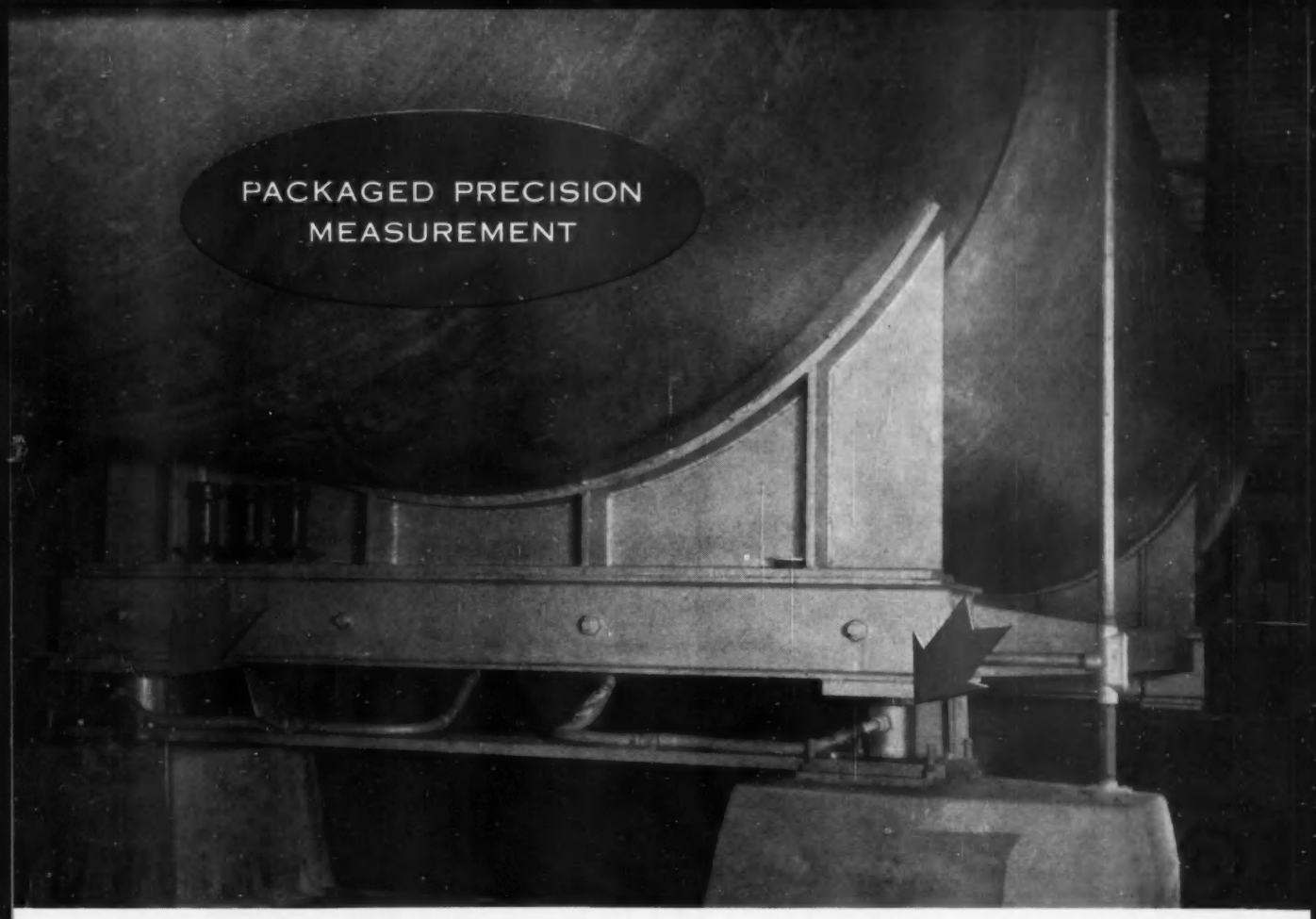

Stanley Home Products, Inc. checks Freon losses as

Two tiny SR-4® Load Cells weigh 200,000 lb. tanks automatically

Baldwin's "Packaged Precision Measurement," neatly solved the handling of large volumes of Freon at the Stanley Home Products plant in Easthampton, Mass. A constant record of stored and used quantities was needed to avoid excessive leakage and evaporation losses.

Continuous automatic weighing of their two 15,000 gallon storage tanks with Baldwin SR-4 Load Cells answered Stanley's problem perfectly. Two small SR-4 compression-type 50,000 lb. load cells were installed as supporting members on the concrete base at one end of each tank. These support exactly half the load of the 200,000 lb. tanks and the instruments are calibrated to read only the weight of the Freon in the storage tanks.

Reinforced flexible hose at inlet and outlet eliminates effect of connecting piping on weighing accuracy.

This Baldwin system gives Stanley weighing accuracy within ½ of 1% of scale (200,000 lbs.). Baldwin-engineered instrumentation provides remote indicators at the tank car siding and recorders at a centralized control panel. The weighing system controls a motor-driven pump at the siding, shutting it down automatically when the tanks have 13,500 gallons of Freon.

Packaged Precision Measurement can solve similar problems for *you*. For detailed information on SR-4 Device applications and instrumentation use coupon today.

Eddystone Division

BALDWIN - LIMA - HAMILTON

Baldwin strip chart recorders on wall (lower photo) show rate of consumption of Freon. Recorders are connected by electrical cables to SR-4 Load Cells under one end of 15,000 gallon tanks on other side of wall (upper photo).

Dept. 3365
Baldwin-Lima-Hamilton Corp.
Philadelphia 42, Pa.
(In Canada: Peacock Bros., Ltd., Montreal, Quebec)

Please send me the following new literature

- ☐ Bulletin 4300 (Introduction to SR-4 Devices)
- ☐ Bulletin 4301 (SR-4 Load Cells and Load Beams)
- ☐ Bulletin 4302 (SR-4 weighing of tanks, bins, hoppers)
- ☐ Bulletin 4306 (SR-4 Fluid Pressure Cells)

Name_____ Title_____

Company_____

Address_____

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FIRST instrument system BASIC GRAPHIC-PANEL

It's BRISTOL'S new metagraphic instrument system

A WIDE SELECTION: For example, there are 35 receiver and 34 controller models and the widest variety of transmitters on the market. A model can be found among these that will exactly meet any requirement.

FULL PLUG-IN SERVICE: Change recorder to an indicator or vice versa in 10 seconds with ABSOLUTELY NO INTERRUPTION WHATSOEVER TO AUTOMATIC CONTROL.

Pull complete chassis out (one piece chassis — no tools required). With chassis removed you get the same automatic control as before.

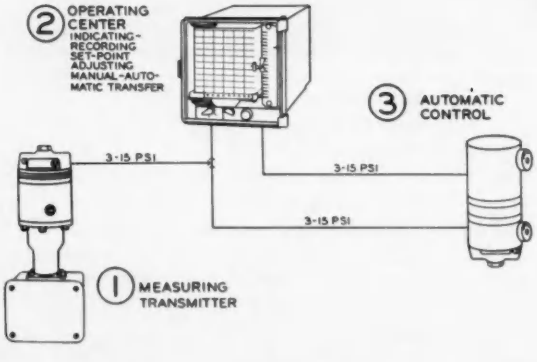
Change from one model to another or if trouble is suspected in a plug-in unit, the doubtful unit can be replaced by a spare while the suspected unit is checked in the service shop — out-of-service time is thus eliminated.

CONTINUOUS VALVE POSITION INDICATION on *same instrument scale as set point scale*, gives continuous data on control valve position—makes "bumpless" transfer possible, simply by matching pointer positions — no need to read actual scale values — minimizes reading errors — speeds operations.

METAGRAPHIC TRANSMITTER

SUPPLIED IN A VERY WIDE VARIETY OF SPANS AND RANGES: For example, absolute pressure instruments are made in ranges as low as 5mm mercury absolute. Pressure instruments as low as 5 inches water to 10,000 psi. Over-range protection available up to 400% over range.

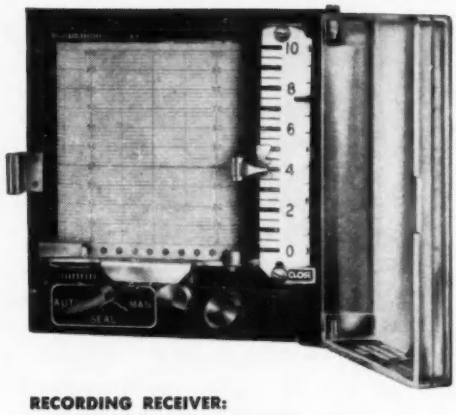
STANDARD BRISTOL MEASURING ELEMENTS ARE USED — high torque, wide-angle travel gives powerful, positive operation. Very sensitive — as little change as 0.03% of range, including reversal.



METAGRAPHIC INSTRUMENTS MEASURE, RECORD, INDICATE, AND AUTOMATICALLY CONTROL

Pressure	Liquid Level
Vacuum	Flow
Absolute Pressure	Temperature and
Differential Pressure	Mechanical Motion

that carries out idea completely!



RECORDING RECEIVER:
Also furnished as an Indicator

NO INTERRUPTION WHATEVER TO AUTOMATIC CONTROL when receiver chassis is removed. The chassis of a Metagraphic Receiver is plug-in construction and can be changed from a recorder to an indicator or back in a matter of 10 seconds.

OFFERED FOR UP TO 3 MEASURED VARIABLES — with air pressure regulators or air-loaded regulators — three-position manual-automatic transfer valves for automatic control and *six-position (on the same knob) transfer valves for cascaded control.*

ALL MEASUREMENTS ON SAME SCALE PLATE: Deviation of pointers shows at a glance conditions of control — no need to read scale.

CONTROLLER
Plug-in Flexibility

VARIETY AND FLEXIBILITY: The most flexible and complete line of controllers offered — 34 different models, including the following variations:

1. Remote set-point
2. Integral set-point (with or without air-loading)
3. Pipe-connected
4. Plug-in receiver mounted
5. Plug-in pipe or surface mounted
6. Five models of control action as follows:
   a. On-Off
   b. Adjustable proportional
   c. Adjustable proportional plus reset
   d. Fixed proportional plus reset
   e. Proportional plus reset plus rate (derivative)

Write for our product data sheets. The Bristol Company, 101 Bristol Road, Waterbury 20, Conn.

6.5.2

BRISTOL'S

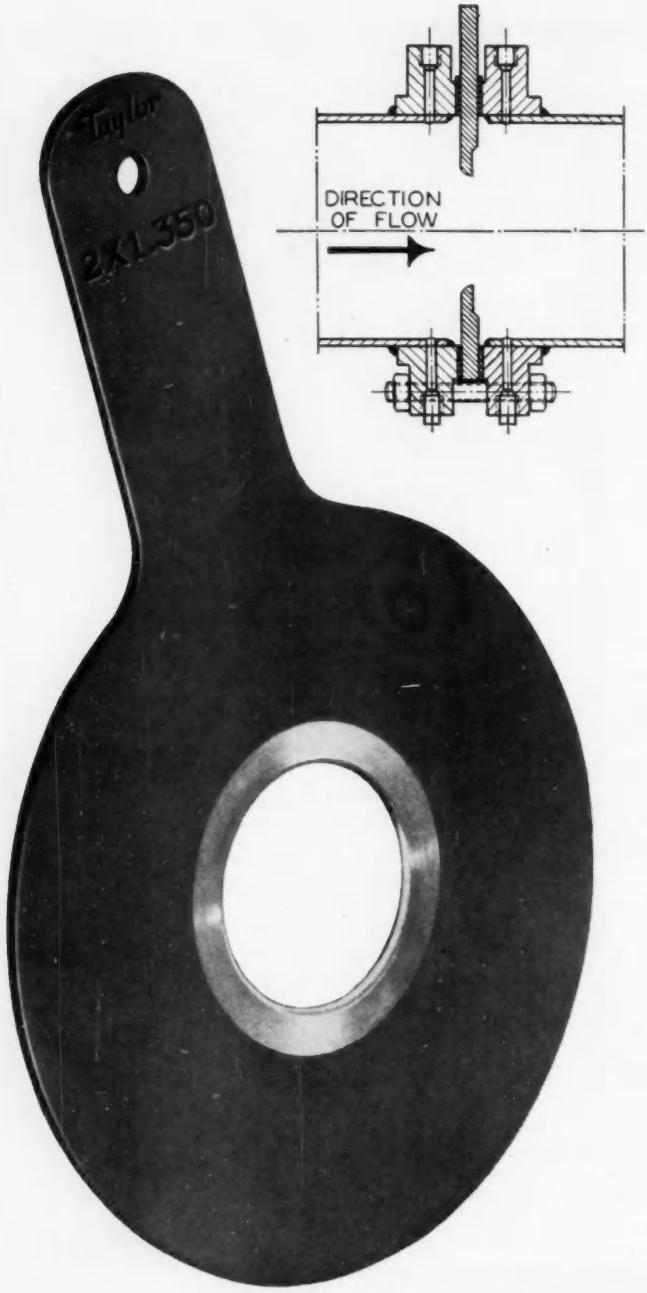
BRISTOL

POINTS THE WAY IN HUMAN-ENGINEERED INSTRUMENTATION

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

New improved measurement of

LOW FLOWS WITH VARYING VISCOSITY



AS A RESULT OF TAYLOR'S BROAD EXPERIENCE WITH QUADRANT EDGED ORIFICE

THE Quadrant Edged Orifice is the result of considerable effort to find a primary element suitable for low Reynolds number flow measurement. This type of flow is encountered when viscosity is a factor both in magnitude and variation. The orifice edge has a rounded approach on its upstream face making it practically insensitive to viscosity changes so long as the throat Reynolds number does not exceed 250,000. For all practical purposes it has a constant coefficient over the Reynolds number range of 5000 to 250,000. Calibration curves are therefore unnecessary—standard square root charts can be used even on low flows. This constant coefficient characteristic permits the use of an integrator in the recorder or a planimeter with the charts.

Our experience has shown that unusual machining skills are required to produce this type of orifice satisfactorily—the edge contour being extremely important. If you have flow measurement problems that could benefit from the use of this Quadrant Edged Orifice, we suggest you submit them to Taylor for analysis and recommendation. Meantime write for technical bulletin to Taylor Instrument Companies, Rochester, N. Y., or Toronto, Canada.

• • •

Instruments for indicating, recording and controlling temperature, pressure, flow, liquid level, speed, density, load and humidity.

Taylor Instruments MEAN ACCURACY FIRST

Will Legislators Probe Control?

Members of Congress may soon get their feet wet in automatic control. Hint of this came more than two months ago when the Congressional Joint Economic Committee listed "automation" for future study by its economic stabilization subcommittee. And now the project seems almost a certainty.

The big impetus came last month in Washington in a crowded, one-day conference conducted by the CIO Committee on Economic Policy on "the meaning and implications of automation."

CIO Puts It On the Line

CIO timed its Washington session superbly. It came just a week after start of contract negotiations with Ford and General Motors over the guaranteed annual wage (GAW). It also coincided with return of congressmen from their Easter recess. And the panel included a stellar senatorial speaker: Joseph O'Mahoney, who steered the New Deal's temporary National Economics Committee, and who is now a member of the joint Senate-House group that is planning the probe.

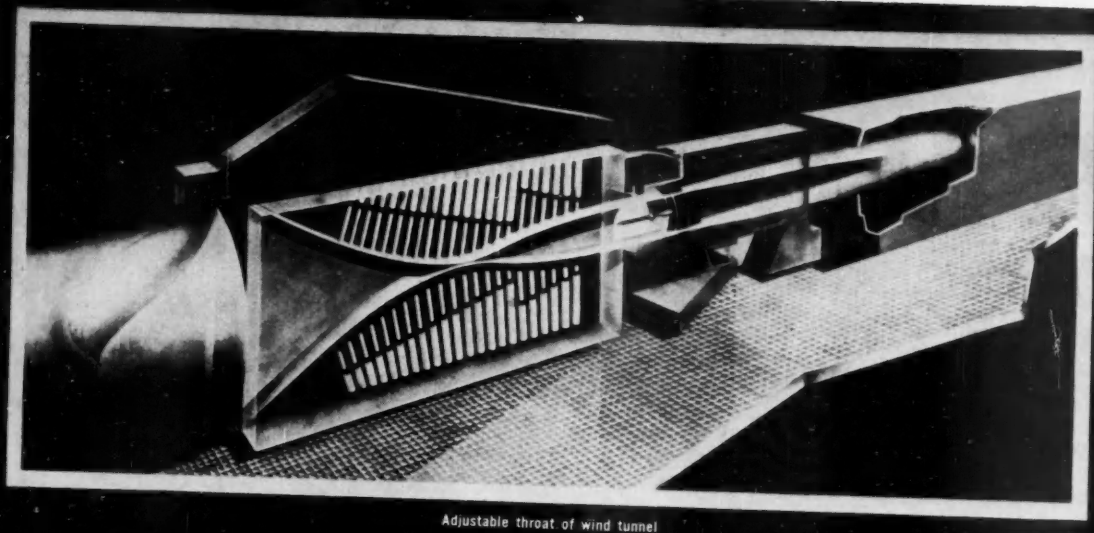
Behind the conference was an implicit challenge. If Management won't accept the economic responsibilities (GAW and permanent lay-off compensations), then the unions will take their problems to Congress for hearings and legislative action.

But not all speakers or guests were quite sure how dire the economic facts are. The unions' mixed feelings were best summarized by Communication Workers' president Joe Bierne. "We believe," said he, "in automation. We welcome automation. We encourage automation. But we do not do these things with our head in the sand." Bierne then let CIO hair down. "Sometimes," he blurted, "we get the idea that engineers have no knowledge of human feelings. Our strong views are emotional because we look at people first."

Senator asks: Is Control Stabilizing?

Senator O'Mahoney was all for heads out of the sand at a national level. "If automation is to turn workers out on the streets," he cautioned, "public policy dare not ignore it." A Congressional study would make certain that "automation would be a stabilizing and not a disturbing element in the national economy."

But the meeting was not merely a platform for union views. In fact, summations by guest expert Don Campbell rebutted these views.



Adjustable throat of wind tunnel

One of the 48 servo amplifiers

Control board and amplifier

ELECTRONS, INCORPORATED

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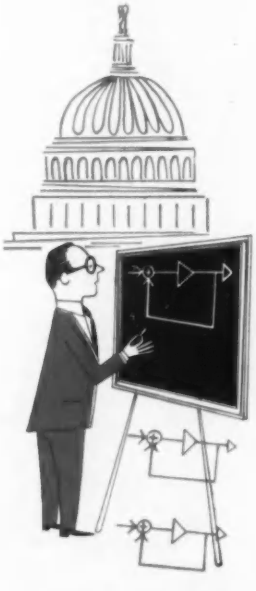
96 Electrons' EL C3J/A thyratrons in 48 servo amplifiers have reliably controlled the adjustable throat of the Cal Tech Jet Propulsion Laboratory's wind tunnel since installation in 1950.

"The scientific theories which can guide us into an entirely new era of production and service capability as a nation are proved," lectured MIT's Campbell. But, he warned, "in spite of the new technology there may be a limitation in our engineering capacity to produce. Many of our plants and processes are so outmoded that automatic controls cannot be installed on them. To engineer new plants and processes takes many, many hundreds, even thousands of engineering man-years of work. I see no rapid impact of automation on the labor force of the U. S. In fact, I urge you to get it going as rapidly as possible so that old-fashioned industries and outmoded operations can improve their competitive position."

Engineer Campbell also lit into the statistics on production vs. employment which some union men were citing. One citation: a 65 per cent increase in steel production, with a 10 per cent decrease in total employment. "But how much replacement was there downstream? And who built the machines?" asked Campbell.

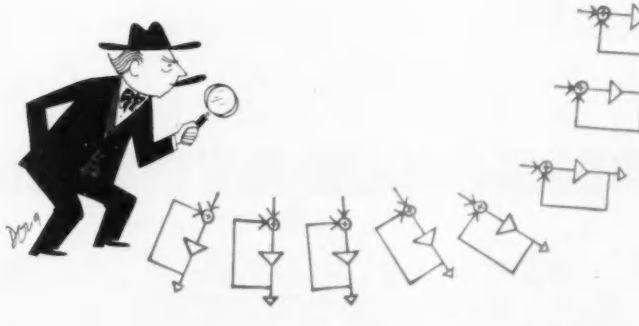
Campbell Stresses Engineering



The fact that differing interpretations can be placed on the same data should serve to pinpoint as well as prompt the forthcoming congressional study. Such questions might be asked: Is labor in total really displaced? What about new technical man-hours and expanded distribution? How necessary is automatic control to future security and well-being?

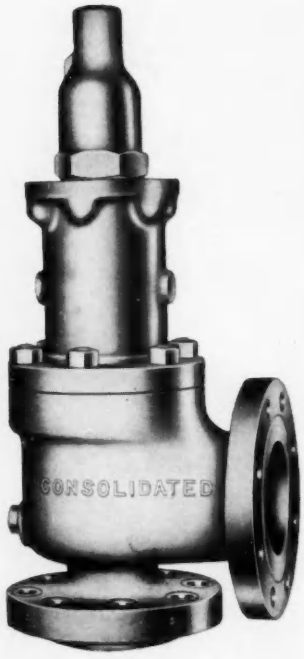
However, many cynical Washington observers already look for a committee report more preoccupied with political nuances than objective evaluation of a great new technology. They believe it will echo this finding of the temporary National Economic Committee:

"Thus, productivity itself—probably the outstanding gain from the economic application of technology—has been harnessed to the interests of a relatively small number of recipients of capital income, to the disadvantage of consumers and workers and to enterprisers and investors excluded from easy access to new technical discoveries."



NOW... CONSOLIDATED SAFETY RELIEF VALVES in economical "2 in 1" design

Peak performance . . . positive valve action assured . . . even where discharge lines are long, or low "superimposed" back pressure exists in the relieving system.



"Two-In-One" design, improved performance . . . the new Consolidated Safety Relief Valve is the result of over 4,000 flow tests in 5 years at West Edmond, Oklahoma. At the A.S.M.E.-approved testing station there, natural gas is available in flow capacities up to 35,000 cfm and pressures up to 500 psig. The A.S.M.E.-approved conditions, apparatus, and procedures permitted Consolidated engineers to test-develop and prove the full range of valve sizes and pressures in both Standard and Bellows designs.

Interchangeability is so highly developed that the majority of Consolidated Standard Valves can be converted to the Bellows design, in the field, simply by installing the bellows. Each type has fewer functional parts than other comparable safety relief valves. Standardization of inlet and outlet center-to-face dimensions permits interchangeability with a large proportion of the valves of other manufacturers. Incorporated is an optically-ground flat seating surface that contributes to easier, more economical maintenance.

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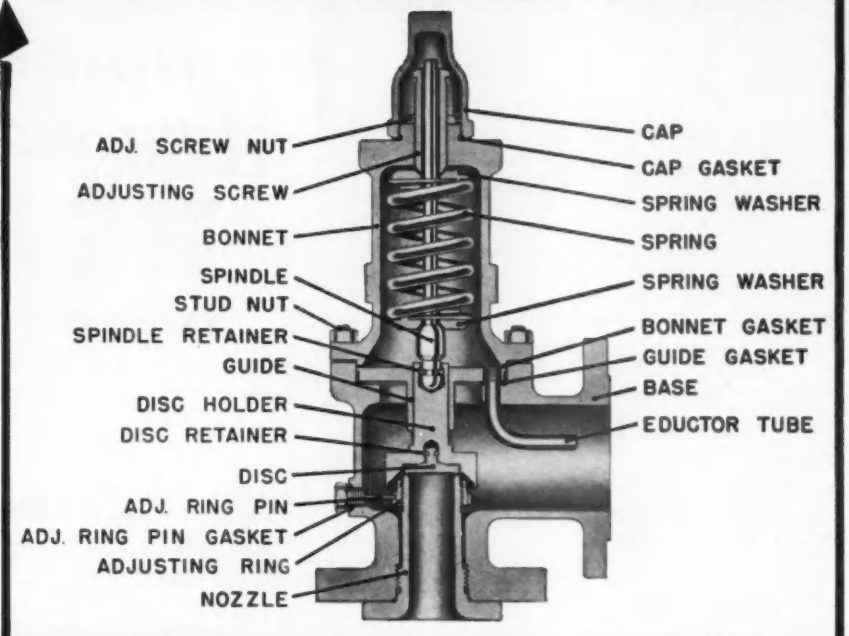

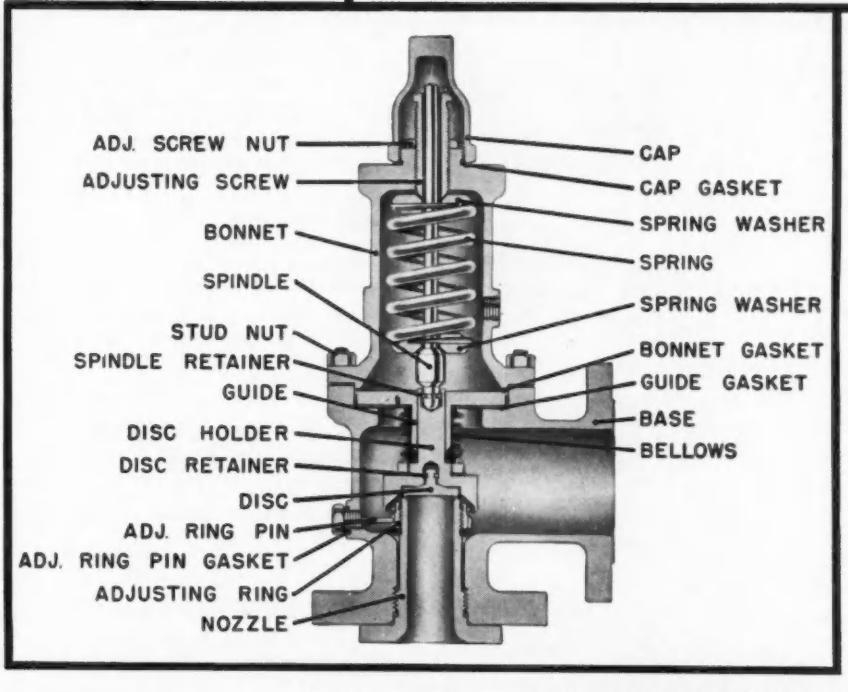

BELLOWS VALVE is like the Standard but has a durable, two-ply stainless steel sealing bellows which effectively isolates from the valve's working parts any contaminants, corrosion, or viscous fluids. The bellows is balanced with the seating surface: set pressure of the valve is not affected by back pressure, whether constant or variable. Consequently, smaller discharge piping can be used, thus reducing the cost of pressure-relieving systems.

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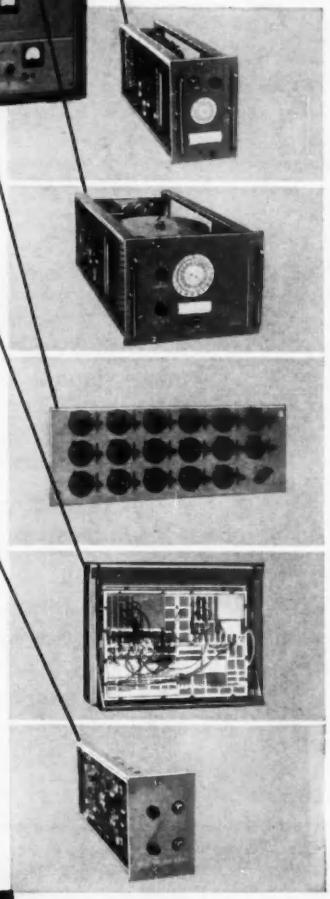

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Control
ENGINEERING
JUNE 1955

Needed: Technicians Abroad

We are an American industrial publication and most of our readers live and work in the United States and Canada. But a surprising number ply control engineering beyond the borders of this continent. There is significant difference in letters we get from near and from afar.

Domestic feedback is clear cut. We are assured that the American frontiers of control are in development and application engineering. Appropriately, our editorial scope parallels the new and projected training of American engineering societies: we are concerned with interpreting the theories of automatic control into engineering principles for the broadest possible application.

Letters from overseas, however, are troubled. In most of western Europe the advance of industrial activity and the problems incident to control are much like those in America. But in countries that are undergoing an industrial awakening, the situation is far different. In these countries control engineers constitute a small minority. Yet they are outspoken pioneers. Many have studied in the United States and in England. They say their problem is not in development and application, but rather in the urgent need for technicians and maintenance men for their installations.

From Norway we hear, "The lack of trained technicians is right now felt as a great obstruction to further automatization. Among other things, varied selection of instruments and controls is needed to give the technician the necessary practical instruction. This would be remedied effectively if industrial control companies in the U.S.A. would cooperate in sending a traveling school to Europe. The school would make publicity for a more extensive use of controls and it might consequently prove to be a sound investment."

Our Norwegian correspondent makes a constructive proposal. Basic training for technicians and mechanics in the United States is well established. In-company training programs, manufacturers' schools, society clinics, trade school courses—all offer sound means for upgrading the ambitious technician. Control engineers in America can pursue their opportunities at the engineering frontier with assurance that there will be well-qualified technicians to operate and service the controls they develop. The same could be true in Norway, South Africa, and elsewhere.

Who would set the necessary machinery in motion? UNESCO? Point Four? Scientific Apparatus Makers Association? The basic ingredients—years of background experience in training technicians—are here in abundance. The next step is for some alert agency to bring them together and "package" them for export.

THE EDITORS

HERE'S A BASIC CONTRIBUTION
TO THE ART OF DYNAMIC ANALYSIS:

Determine System Dynamics— Without Upset

J. B. RESWICK, Massachusetts Institute of Technology

THE GIST: The first step in constructing a mathematical model of a control system is to determine the dynamic characteristics of its operating components. Usually this is difficult to do analytically. So the designer resorts to experiment. He disturbs the component or "plant" with sinusoidal variations or sudden steps and impulses and records the response.

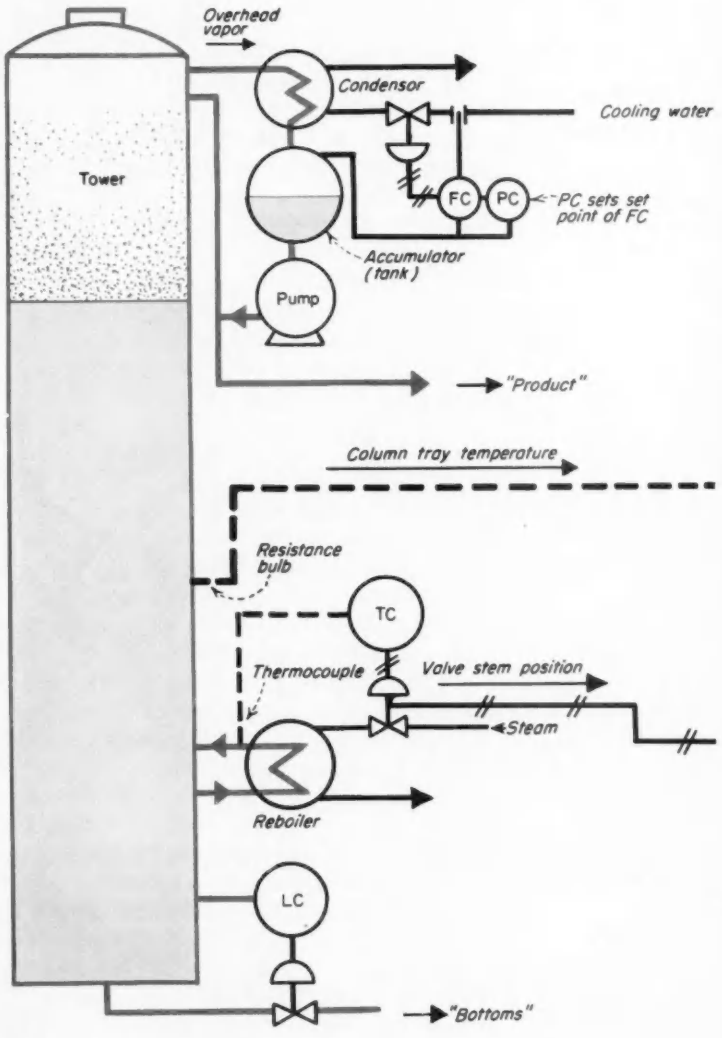
While the disturbance-response technique has had considerable success, it has two practical drawbacks:

▶ It usually disturbs the system enough to upset its equilibrium. This can mean off-quality product in a plant or poor performance in a system.

▶ Often, variations caused by effects other than the one under study may obscure the required information.

For these reasons many investigators (Y. W. Lee[2], Levinson[3], Tustin[4], and Lewis[5]) have studied ways to extract the needed information without disturbance. The concepts involved — impulse response, convolution, and correlation — are presented step-by-step in this article. But the article goes one step further: it describes the Delay Line Synthesizer, a new tool which operates on the auto-and cross-correlations of input and output data to determine dynamic relationships quickly and easily.

Using his Delay Line Synthesizer, Author Reswick publishes the first practical application of this new method of dynamic analysis to a production processing plant. His ASME paper[1] applies the method to the human operator.



THE APPLICATION

Figures 1 and 2 describe the test set-up, a refinery distillation column and its automatic controls. And the input-output data are presented as actually derived during test.

In the system, reboiler outlet temperature is held constant by a controller automatically valving the amount of steam supplied. Column pressure is controlled by regulating the flow of cooling water to one of the two parallel condensors on the overhead product.

Without disturbing column equilibrium in any way, a high speed recorder makes synchronous records of:

- Stem position of the valve on the steam supply to the reboiler
- Temperature on a tray one-third of the way up the column

The chart section shows 8-1/2 minutes of the two records. The temperature variation is small, and is subject to random steps. The valve stem position oscillates at a (relatively) high frequency. A mean curve, drawn by eye, averages out the oscillation for the purpose of correlation computations.

For the full story on how the method and its tools are developed and applied, and for the important results of this weighting function study, dig into the following article.

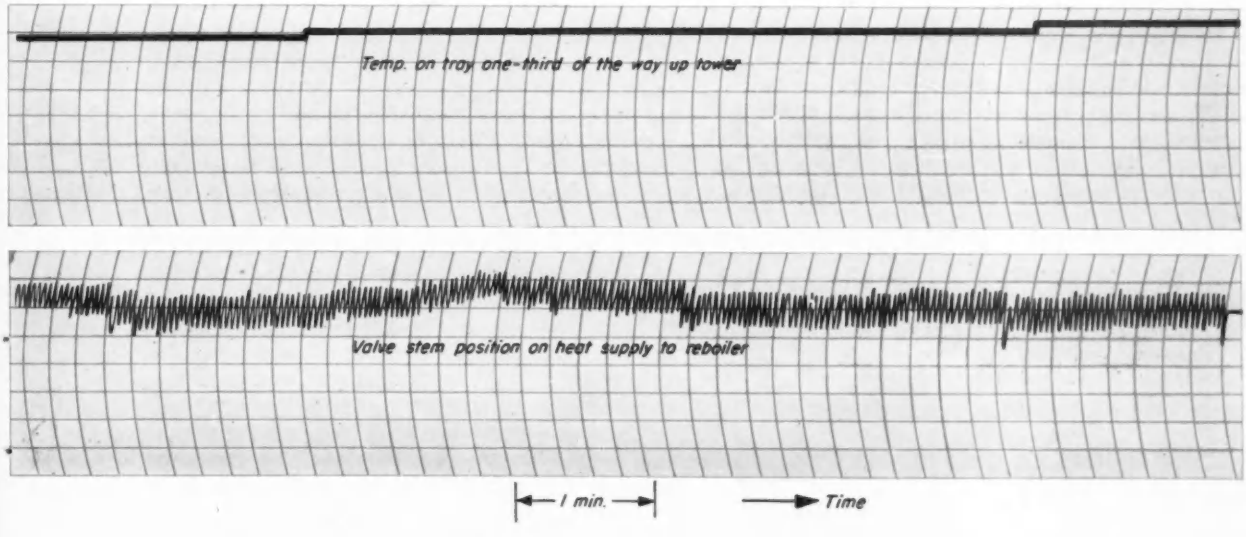
THE METHOD

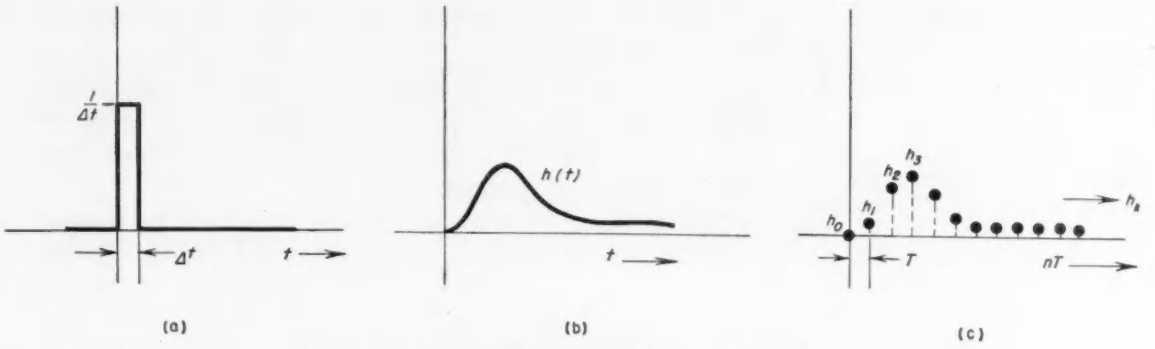
IMPULSE RESPONSE—An impulse is the limiting case of a large disturbance of very short duration. A *unit impulse* is defined as one for which the area under the curve of magnitude vs. time equals unity in a given set of units. Figure 3 (a) shows schematically a unit impulse as input to a component of a control system, and Figure 3 (b) shows the corresponding output. Strictly speaking an impulse is the limiting case of the pulse shown in Figure 3 (a) as $\Delta t \rightarrow o$. In practice, however, an input with small but finite Δt and unit area gives an output almost identical to the response to a true unit impulse.

For any linear system, the *impulse response* $h(t)$ is defined as the response of the system to a *unit* impulse starting at time $t = o$. If the impulse

Legend

FC – *Flow controller*
PC – *Pressure controller*
TC – *Temperature controller*
LC – *Level controller*





(a) (b) (c)

Time sequence representation of impulse response. FIG. 3

response is known, the response of the system to an impulse of any other strength is in simple proportion. The response to an impulse at any other time is found simply by shifting the time scale. For computational purposes, $h(t)$ is conveniently represented as a time (or number-in-time) sequence of ordinate values, each separated by a time interval T sufficiently small to retain the essential character of the response. Thus, Figure 3 (c) evolves from Figure 3 (b) and equation (1) is written in sequence form.

$$h(t) = T/2h(0), Th(T), Th(2T) \cdots Th(kT) = h_0, h_1, h_2 \cdots h_k \quad (1)$$

The impulse response of any *stable* system becomes arbitrarily close to zero after a finite length of time. Hence a finite sequence of this form can always approximate the $h(t)$ of a stable system. In this sequence the general term h_n represents the response at time $(t+nT)$ to a unit impulse applied at time t.

Convolution In The Time Domain

To determine the response of the system to an arbitrary input $m(t)$, approximate $m(t)$ by a sequence of impulses, separated in time by the interval T, and each equal in strength to T times the corresponding ordinate of $m(t)$. Accordingly, the response $c(t)$ can be written in series form as the sum of the responses at time t due to all the individual past values of $m(t)$. Thus:

$$c(t) = \sum_{n=0}^{k} h_n m(t - nT) = h_0 m(t) + h_1 m(t - T) + h_2 m(t - 2T) + \cdots + h_k m(t - kT) \quad (2)$$

so that, the response at particular time, t_1, is

$$c(t_1) = \sum_{n=0}^{k} h_n m(t_1 - T) = h_0 m(t_1) + h_1 m(t_1 - T) + h_2 m(t - 2T) + \cdots + h_k m(t_1 - kT) \quad (2a)$$

and at t_2,

$$c(t_2) = \sum_{n=0}^{k} h_n m(t_2 - hT) = h_0 m(t_2) + h_1 m(t_2 - T) + h_2 m(t_2 - 2T) + \cdots + h_k m(t_2 - KT) \quad (2b)$$

Figure 4 shows that the impulse response is plotted backwards or "folded back" on the input in the process of computing $c(t)$ by this means. For this reason, the process is known as *folding* or *convolution*. Since the output at time t is essentially a weighted sum of past input values, the impulse response when used in convolution is called a *weighting function*.

Equation (2) becomes exact when T approaches 0. It is then known as the *folding* or *convolution* integral. The operation on a unit step input in Figure 5 further illustrates the way in which the process of Equation (2) works.

Figure 5 essentially implies that once the coefficients of Equation (2) are made equal to the incremental heights in the approximated step response, the actual response will be produced when the input $m(t)$ is made a step. Since the operation is entirely linear, it must produce the correct response for any input. It is significant that while the impulse response is defined only at discrete points in time, both the input and output are defined continuously. Figure 4 indicates this, for no restriction is placed on the interval between t_1 and t_2, at which time the computation is illustrated.

Thus, the *impulse response* not only completely describes the system's dynamic characteristics, but may be used as a *transfer operator** to calculate an output due to *any* arbitrary input. It thus ranks with the common operational form of a differential equation or the *transfer function*, both of which determine the output due to an arbitrary input.

* The term *transfer operator* designates any operational form relating an output to an input. See Ref. 1 for more detailed definition.

Indeed, these *transfer operators* are equivalent.

Actual computational schemes based on these ideas have been proposed by many investigators, including Tustin[4], Lewis[5], and Paynter[8]. In most of these schemes, the input and output, as well as the weighting function, are expressed as number sequences or equivalent graphical representations. Suitable interpolation functions are often added to produce continuous time solutions.

Discovery of the Weighting Function (De-convolution)

When time series represent an input $m(t)$ and an output $c(t)$ a set of k equations of the form of equation 2 may be formed. The h_n coefficients are the unknowns. Any noise or deviations in $c(t)$ not caused by $m(t)$ makes the set of equations almost impossible to solve directly.

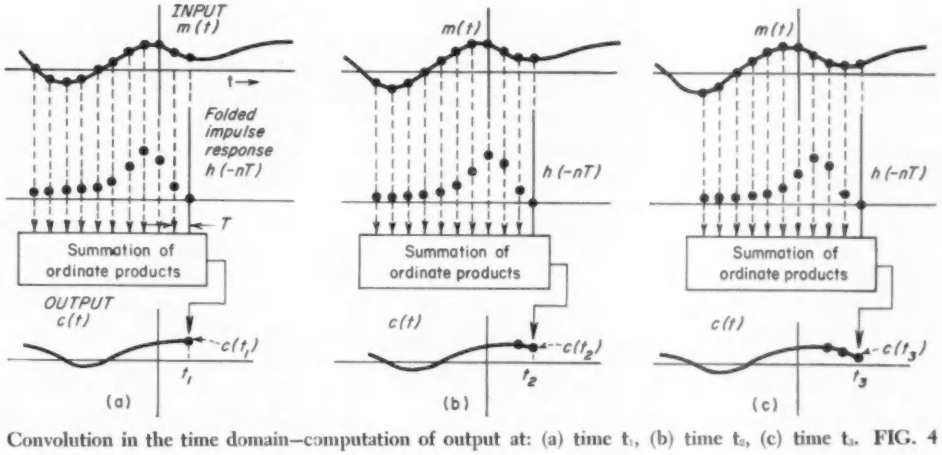
Correlation Functions and Significance

It is possible [1, 2, 4, 6] to transform the input-output records into forms that make the discovery of weighting functions much easier. Auto- and cross-correlations do this. They are curves which retain information on that part of an output due only to a given input, and take on shape characteristics.

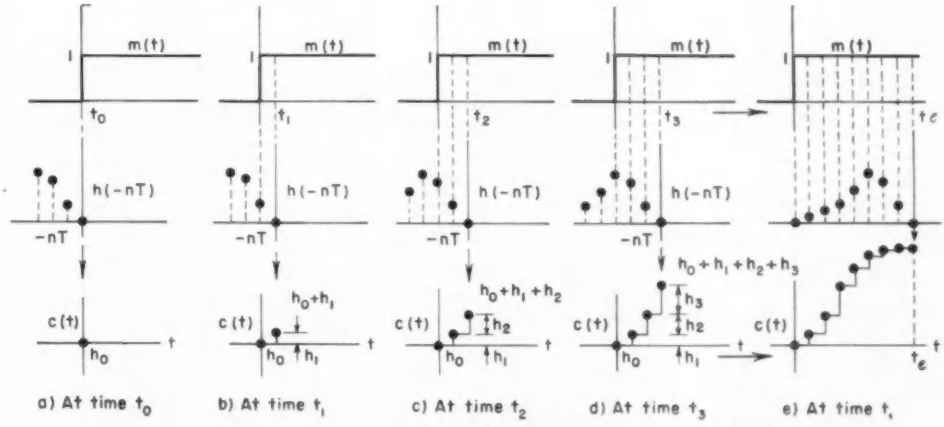
The *auto-correlation* of the input $m(t)$ is defined as the average value of the product of any two values of $m(t)$ separated by the time interval τ. Figure 6 shows how the auto-correlation is determined at various time intervals. Symbol $\phi_{mm}(\tau)$ denotes auto correlation, and a bar denotes averaging in

$$\phi_{mm}(\tau) = \overline{m(t)m(t+\tau)} \qquad (3)$$

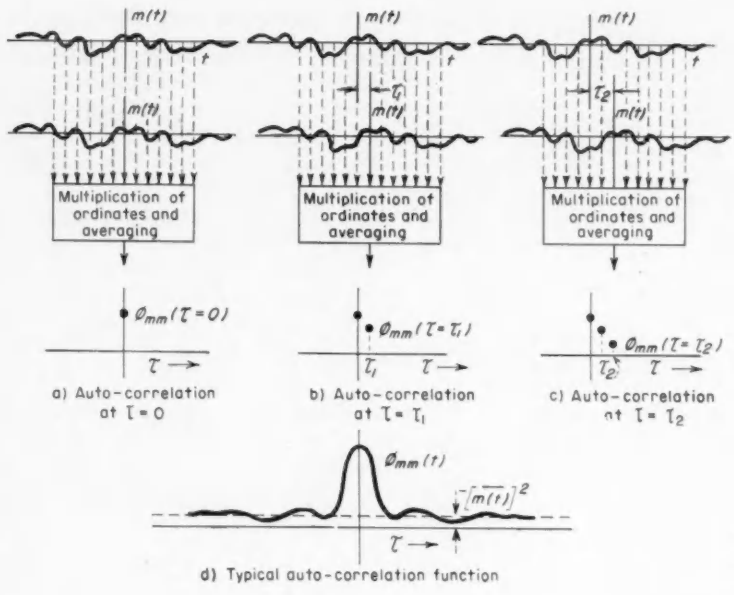
When $\tau = 0$ and the curves are not displaced, the value of ϕ_{mm} is the mean square value of m(t)—the maximum value $\phi_{mm}(\tau)$ may have. As the curves are displaced either to the right or left, the



Convolution in the time domain—computation of output at: (a) time t_1, (b) time t_2, (c) time t_3. FIG. 4



Determination of step response by using the weighting function. The incremental heights in the approximated step response equal the constants in equation 2. FIG. 5



Formation of the auto-correlation function. FIG. 6

variations begin to cancel each other so that as τ becomes large, $\phi_{mm}(\tau)$ becomes constant at a value which is the square of the average value of $m(t)$. (See Figure 6(d).) With the axis chosen so that the average value of $m(t) = 0$, $\phi_{mm}(\tau)$ becomes zero at large values of τ. These remarks apply, only, to random variations. If a regularly varying frequency component is present in $m(t)$, it will also appear with the same frequency in $\phi_{mm}(\tau)$.

The *cross-correlation* of the input $m(t)$ with the output $c(t)$ is defined as the average value of the product of the value of $m(t)$ at any given time with the value of $c(t)$ at a time τ seconds later. The process of forming the cross-correlation is similar to that shown in Figure 6 except that the lower curve is now the output $c(t)$. The solid line of Figure 11 shows a typical cross-correlation curve. Using $\phi_{mc}(\tau)$ for cross-correlation, this is written,

$$\phi_{mc}(\tau) = \overline{m(t)c(t+\tau)} \tag{4}$$

Of the various possible devices for computing auto- and cross-correlations, the most convenient is an automatic digital computer. This is primarily due to the diverse forms in which data are continuously recorded. A large number of closely-spaced ordinates of $m(t)$ and $c(t)$ are recorded. Then the correlations are computed using these formulas:

$$\phi_{mm}(nT) = \overline{m_i m_{n+i}}$$

$$\approx \frac{1}{N+1}\left[m_o m_m + m_1 m_{n+1} + m_2 m_{n+2} + \cdots + m_N m_{n+N}\right] \tag{5}$$

$$\phi_{mc}(nT) = \overline{m_i c_{n+i}}$$

$$\approx \frac{1}{N+1}\left[m_o c_n + m_1 c_{n+1} + m_2 c_{n+2} + \cdots + m_N c_{n+N}\right] \tag{6}$$

where

$m_o, m_1, m_2, \ldots, m_{N+n}$ = successive ordinates of $m(t)$

$c_o, c_1, c_2, \ldots, c_{N+n}$ = successive ordinates of $c(t)$

Equations (5) and (6) are easily, even if tediously, solved by hand. Using a desk-calculator, a correlation curve may be produced in a few hours. Punched-card computers greatly reduce this time. The M.I.T. digital computer (Whirlwind I), computes correlations in about 5 minutes.

C.M. Chang[9] shows that correlations obtained from rather short segments of data are as useful practically in weighting function determinations as those obtained from very long records. The only requirement is that the auto- and cross-correlations be programmed in identically the same way when they are formed. A rough rule, with some experimental verification, is that the input and output records should have a time duration of at least 10 to 50 times the time duration of the significant part of the weighting function. The auto- and cross-correlations should themselves have a duration in the region of positive τ of at least twice the time duration of the significant part of the weighting function.

The weighting function $h_n(nT)$ relates through convolution the correlation functions in the same way as it relates $m(t)$ and $c(t)$. Thus, where

$$c(t) = \sum_{n=o}^{k} h_n m(t - nT)$$

the analogous relation between the auto- and cross-correlations is

$$\phi_{mc}(\tau) = \sum_{n=o}^{k} h_n \phi_{mm}(\tau - nT) \tag{7}$$

A new set of equations of the nature of equation 2 may now be formed in which the h_n coefficients are *still* the unknowns. Levinson[3] shows that such a set

of equations are more amenable to solution. However, these equations are often difficult, if not impossible to solve. Because de-convolution in the time domain has been so difficult, most workers convert to the frequency domain by Fourier transformations. They[2] have established straight-forward techniques that are easy to handle theoretically.

But the simplicity of the frequency domain is not obtained without certain practical limitations.** De-convolution in the time domain is now easily accomplished through use of an analog device described in the following.

** See Reference 1 on the effects of noise in closed loop systems.

THE TOOL

The Delay Line Synthesizer (DLS). The DLS solves the large number of simultaneous equations that define h_n by becoming an electronic model of h_n. It performs convolution on an input voltage that represents the auto-correlation. Since convolution involves an operation on past values of an input, an essential part of the synthesizer is an electronic delay line. This is shown in Figure 7 where a functional block diagram illustrates another interpretation of the convolution process. The present value and past history of the input $m(t)$ are stored in a lumped delay-line. This delay-line is tapped at each of the lumped delay outputs where the values of each delayed input is multiplied by an appropriate constant (h_n) and then summed to produce the output $c(t)$. The process indicated in Figure 7 is exactly that described in Equation (2) and indicated in Figure 5. Not only is the block diagram of Figure 7 useful for visualization, but it also is the basis for the design*** of the delay line synthesizer.

A large number of simple lags in series produce the "imperfect" lumped delay line used. Proven a practical compromise, Figure 8 shows its performance. The transfer operator for each "lump" is

$$\frac{e_{out}}{e_{in}} = \frac{1}{(1+\tau D)^n} \qquad (8)$$

where D = the operator $\frac{d}{dt}$.

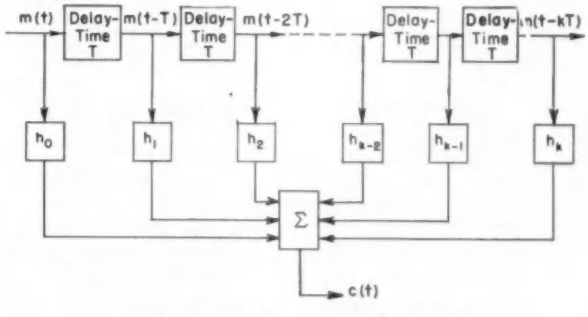
Time scaling and cost considerations have set $\tau = 12$ microseconds and $n \approx 25$ for each of the 20 plug-in delay units used in the DLS.

Figure 9 shows how the *auto-correlation function* $\phi_{mm}(\tau)$ may be generated as a repeating electrical wave form or function. It is then introduced into the delay line synthesizer whose output is subtracted electrically from an electrical function having the shape of the *cross-correlation* $\phi_{cm}(\tau)$. One then systematically adjusts the knobs of the *delay line synthesizer* so that the resulting difference voltage, as repetitively displayed on an oscilloscope, reduces to a minimum. The result is that the delay line synthesizer becomes a model (within its limits) of the system. An impulse applied to it will produce the weighting function which may be photographed.

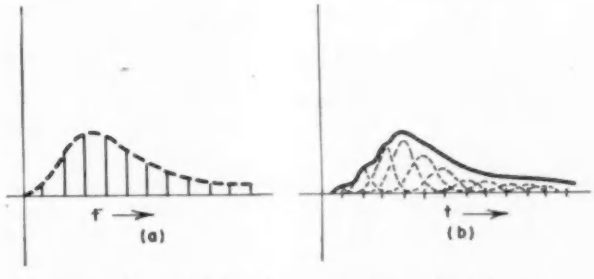
This technique is rapid and convergent for the following reasons:

► The *auto-correlation* function derived from *random* data has a high central peak and goes to zero (or steady state) on either side of $\tau = 0$. In fact, if the input contains all frequencies at the same power level (*white noise*), $\phi_{mm}(\tau)$ is a pure impulse!

► Since the delay line synthesizer performs convolution on a "pulselike" input, each knob affects the output (and therefore the error) at a localized point in time. Thus the operator immediately senses the result of a given manipulation when viewing a repetitively displayed trace on an oscillosocope screen.

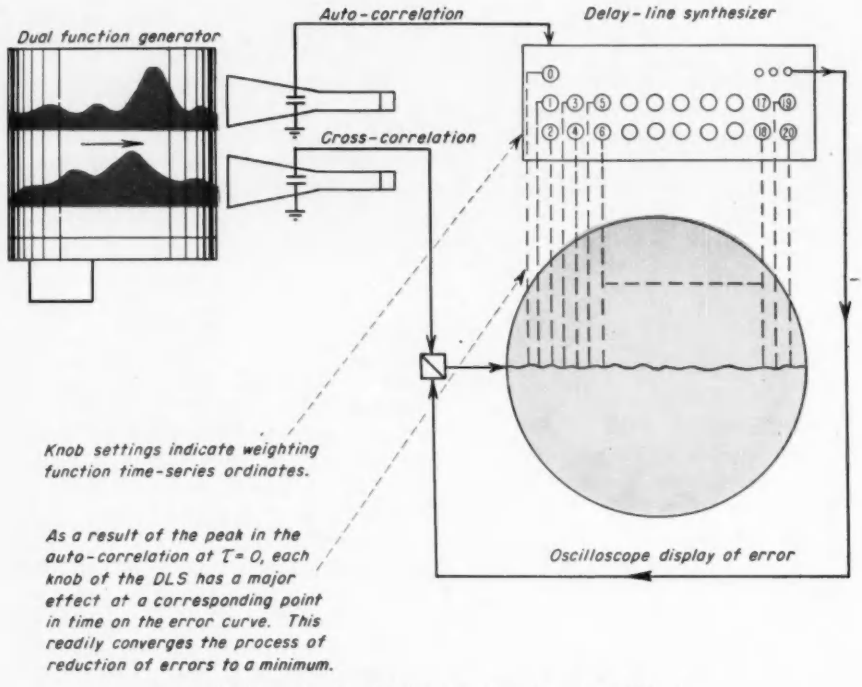


Block diagram of convolution. FIG. 7



If a perfect lumped delay line were used, the electrical output of the DLS in response to a pulse input would appear as in (a). The use of an "imperfect" lumped delay line, where the pulses are "spread-out," permits the creation of a smooth output as in (b). FIG. 8

*** To the author's knowledge the first device of this type was built by J. L. Janssen[10] in Holland. A similar device was built by C. A. Stutt[11] at the RLE, M.I.T. Many of the ideas incorporated in the delay line synthesizer described here were suggested by George A. Philbrick of George A. Philbrick Researches, Boston, Mass.

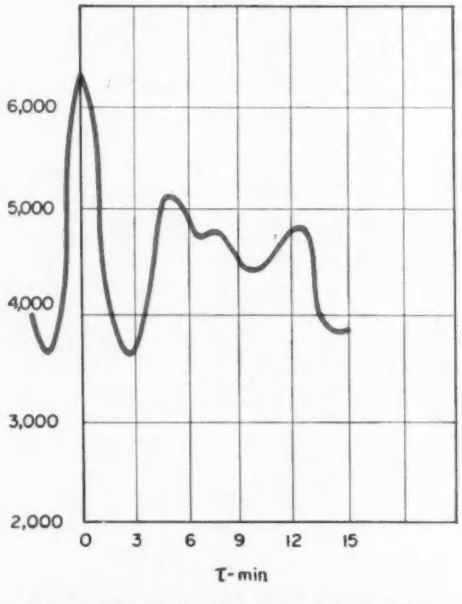

Auto-correlation
Delay-line synthesizer
Dual function generator
Cross-correlation
Knob settings indicate weighting function time-series ordinates.
As a result of the peak in the auto-correlation at τ = 0, each knob of the DLS has a major effect at a corresponding point in time on the error curve. This readily converges the process of reduction of errors to a minimum.
Oscilloscope display of error

Block-schematic of weighting function discovery. FIG. 9

► The error-reduction or convergence process is conducted by a human being who looks at the complete curves and not at a time series representation, as would be required in a digital computer. He therefore works with a great deal more information. In addition, the human being is not bound by a mathematically defined error criterion. He is always able to converge on a "best" linear weighting function.

APPLYING THE METHOD AND THE TOOL

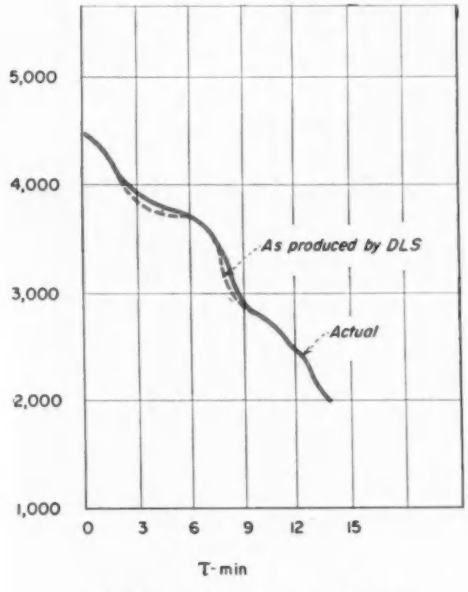
Discovering an Important Weighting Function In a Refinery Distillation Column. Turn back to the application on the first page of this article. Using the described method and tool produces the auto-correlation of the valve stem position in Figure 10. Figure 11 shows the cross-correlation of temperature with valve stem position. This figure also reveals the output of the DLS when properly adjusted to operate on the auto-correlation as an input voltage variation. Figure 12 shows the frequency response obtained from the DLS.



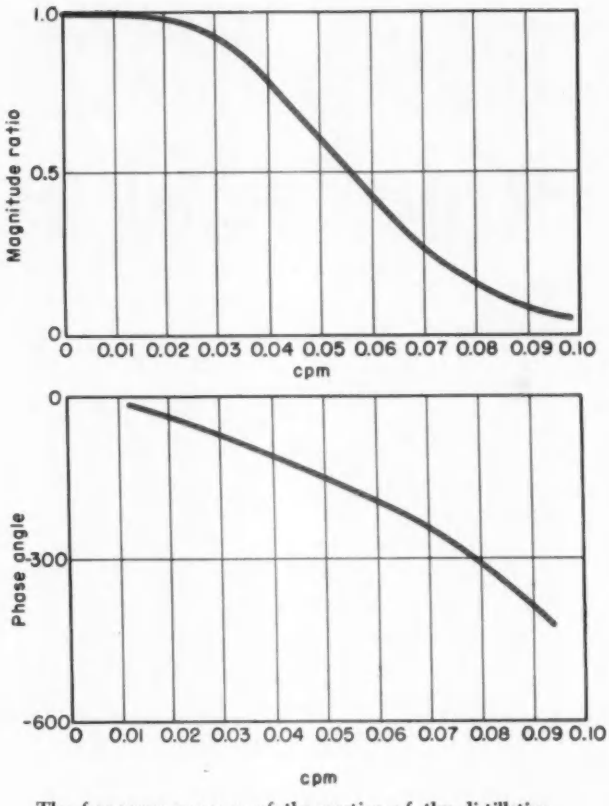
Auto-correlation of valve-stem position. FIG. 10

With the exception of the industrial application, the material presented in this article has been condensed from a paper presented at the ASME-IRD Conference on Automatic Control, April 25-26, 1955, at the University of Michigan, Ann Arbor, Mich.

The author is indebted to The Foxboro Co., Foxboro, Mass., which obtained the original normal operating records and made them available for study.



Cross-correlation of temperature with valve-stem position. FIG. 11



The frequency response of the portion of the distillation column tested is determined by finding the frequency response of the DLS. FIG. 12

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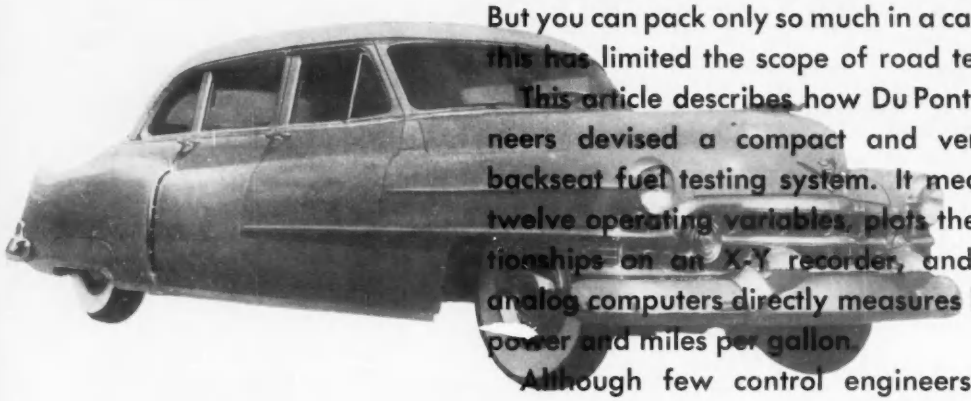
Backseat Computer Rates Fuel in Action



THE GIST: How does an automotive fuel really perform? The facts can be gleaned either on the road or in a test stand. Road information is direct and more authentic. A great deal of complex equipment must be set up to simulate a highway in the lab. But you can pack only so much in a car, and this has limited the scope of road testing.

This article describes how Du Pont engineers devised a compact and versatile backseat fuel testing system. It measures twelve operating variables, plots the relationships on an X-Y recorder, and with analog computers directly measures horsepower and miles per gallon.

Although few control engineers may want to clutter their own cars with this precision system, its techniques may suggest solutions to many a workaday problem.

K. G. PARTHEMORE and R. A. SPRAKER,
E. I. du Pont de Nemours and Co.

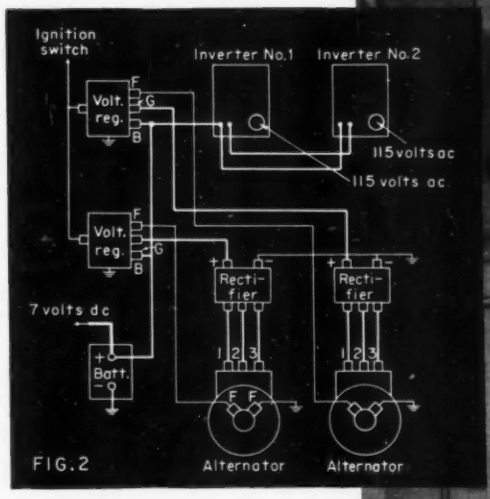
Evaluating the performance of fuels and lubricants in an automotive engine is a recurring study in the Du Pont petroleum laboratory. The ideal way to gather basic data is in direct road test. If enough information is developed on the road, proper laboratory conditions can handle further routine tests.

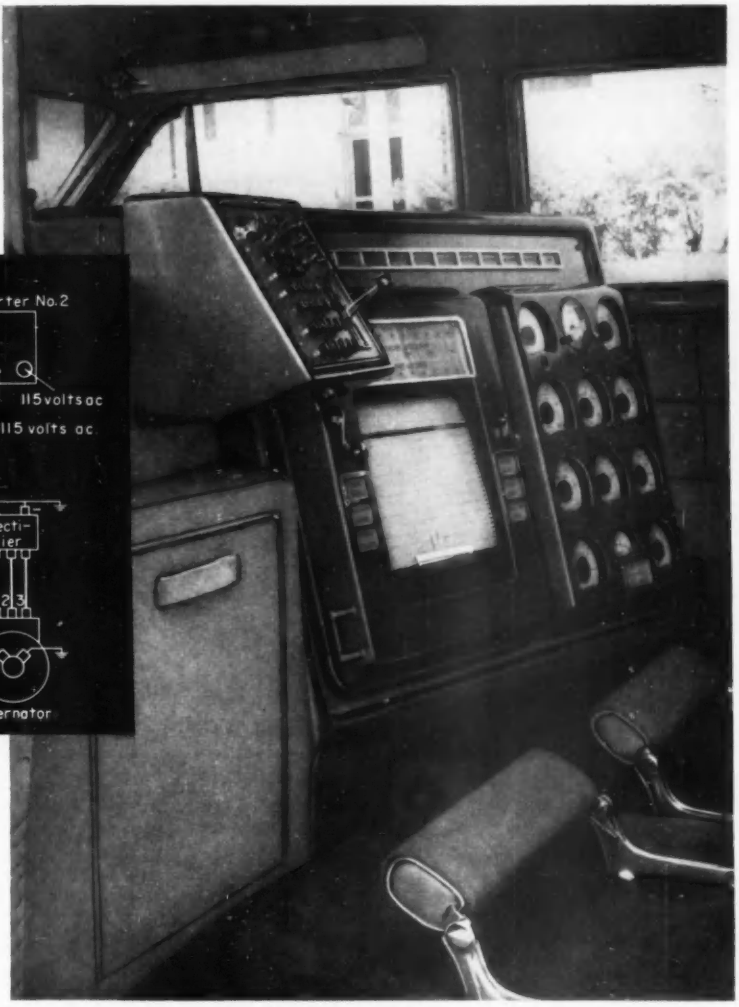
In designing our road test equipment a system was conceived which would perform most measurements normally made on a first rate laboratory test stand. A spacious 1952 Cadillac seven-passenger sedan was chosen to house the system. As it turned out—with all functions in—there was still enough room for test engineers to sit in comfort.

On an instrument panel to the right of the driver and facing the passengers a battery of twelve circular face indicators register operating variables and a two-axis recorder interrelates these variables during test. An adjacent panel lets the operator select a specific fuel from storage tanks and the variable he wants to plot. He can also control engine spark timing through a panel-distributor hydraulic link.

Scope of the Instrumentation.

The indicated engine variables divide into two general groups: (1) those directly measured from primary sensing devices, and (2) those electrically





Backseat test system Fig. 1 and the special equipment furnishing its power. Fig. 2

computed from combinations of directly measured variables. The table shows the devices used and the computation relationships:

1) ENGINE VARIABLES AND THEIR PRIMARY SENSING ELEMENTS.

Variable	*Sensing Element*
Torque	Strain gages on axle
Road Speed	Tachometer generator
Fuel Flow	Transmitting rotameter
Spark Advance	Ignition spark and magnetic pickup
Temperature	Thermocouples
Throttle Position, Basic Spark Setting	Transmitting slidewire

2) COMPUTED VARIABLES.

Computed Variables	*Relationship*
Horsepower	Constant × Miles per Hour × Torque
Miles per Gallon	Miles per Hour ÷ Fuel Flow in gph

In addition to these indications, temperatures at six different points in the car are sensed by thermocouples and read by pushbutton on a millivoltmeter on the instrument panel. Also, the panel indicates exhaust pressure and intake manifold vacuum.

The electrical power requirements of this extensive system proved to be far beyond normal capacity of the automotive generating equipment. Besides the extra 7 vdc needed for panel ventilating fans, special fuel pumps, tank switching solenoids, and indicating lights, an auxilliary 300 watts of 100 v, 60 cycle ac power were required for the electronic instruments. Hence the conventional generating system was replaced by the special system shown schematically in Figure 2.

In the new power circuit two Model 5158-GE

Leece-Neville alternators, arranged in tandem on a common shaft, are pulley driven from the fan belt in the conventional manner. Dry plate rectifiers convert ac to dc. The dc output is held at 7 v by voltage regulators controlling the alternator field currents. The regulators also provide tapered charging for the storage battery across the dc line.

The special power system has an output capacity of 175 amps at 7 v as compared to the 40 to 50 amps from a conventional automotive generator. It also has the added value of being able to charge batteries and run accessories while the engine idles. In a standard system the battery discharges under idling conditions.

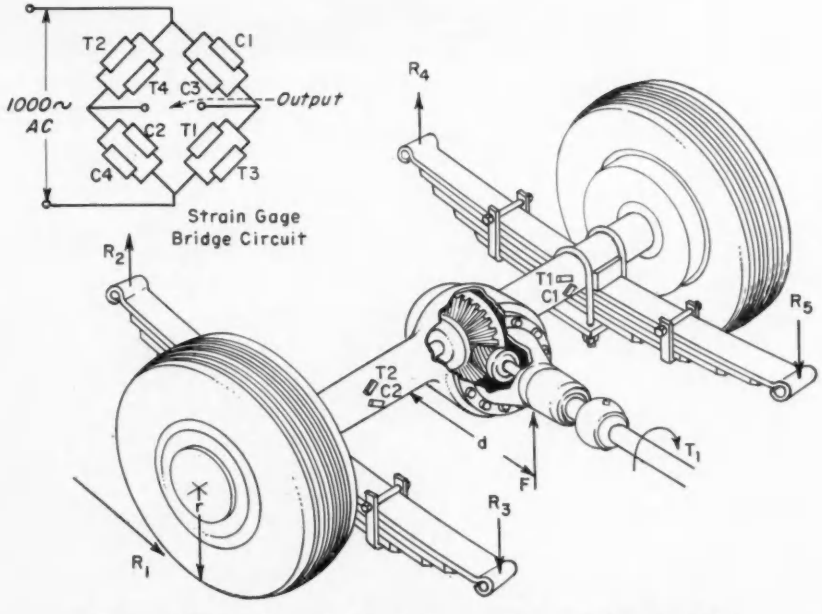
Inverters derive the 115/60 ac needed to run the electronic recorders from the 7 vdc supply. Two ATR Model 6THSF inverters are used. Power conversion is made in the inverters by the vibrator-transformer method. Each unit has a continuous duty output capacity of 150 watts.

The following sections describe the instruments and circuits for measurement and computation.

HOW THE SUBSYSTEMS FUNCTION . . . TORQUE

The torque used in computing the useful power delivered by the engine is equal to the product of the road reaction in pounds and the rear wheel radius in feet. The diagram, Figure 3, shows how the rear axle housing secures to the car frame by the rear springs. Rear wheel torque is measured by strain gages bonded to the rear axle housing [1,2].

How stresses proportional to rear wheel torque are imposed on the rear axle housing is best understood by considering the forces that act on the assembly. Drive shaft torque, T_1, delivered by the engine, drives the rear wheels through the pinion, ring gear, and the rear axles. Road reaction, R_1, and rear wheel radius, r, constitute a torque that acts through the rear axles and ring gear to exert an upward force on the drive shaft pinion. This causes the drive shaft to bear upward on the pinion



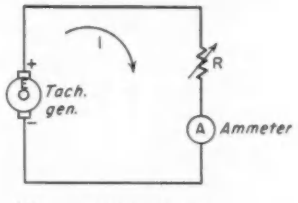
How road thrust is detected by strain gages in the rear axle housing. Fig. 3

bearing as indicated by arrow, F. The universal joint in the drive shaft prevents the drive shaft mounting system from offering any restraining torque. Consequently, the torque caused by force, F, acting at a distance, d, from the longitudinal axis of the axle housing is restrained only by reactions R_2, R_3, R_4, and R_5 at the rear spring mooring points. This torque is carried by the axle housing, with bonded strain gages detecting the torsional stresses.

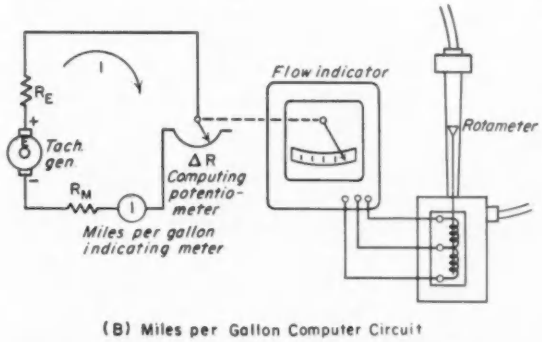
The gages are mounted so that each sensitive axis forms a 45 deg angle with the longitudinal axis of the axle housing. Gages labeled T_1, T_2, C_1, and C_2 appear in their proper positions in the diagram. The torsional stresses previously described place gages T_1 and T_2 in tension and gages C_1 and C_2 in compression. A second set of gages, T_3, T_4, C_3, and C_4 similarly bond to the rear of the housing.

The eight gages connect in the Wheatstone Bridge configuration shown in the upper left hand corner of Figure 3. Resistance changes due to torsional loading cause this bridge to produce a proportional unbalance signal at the output terminals. The bridge is arranged so that strains from bending, lateral or thrust loads on the axle housing affect gages in the same arm in an equal and opposite manner. Gages in different arms, however, react so that the two bridge output terminals stay at the same potential. Thus, no bridge unbalance results from these unwanted effects.

The bridge connects into a Ruge De Forest strain gage amplifier. This amplifier supplies a 1000 cycle ac operating voltage from a vacuum tube oscillator, and receives and amplifies the unbalance signal from the bridge output terminals. A reversal of torque in the axle housing causes tension and compression members of the strain gage bridge to be reversed. This reverses the phase of the torque signal at the bridge output terminals. A phase sensing circuit in the amplifier detects such reversals and provides a dc output signal that represents both magnitude and direction of the applied torque. This torque signal is indicated on a dc microammeter.



(A) Basic Divider Circuit



(B) Miles per Gallon Computer Circuit

Servo driven potentiometer in Ohms Law divided circuit computes miles per gallon. Fig. 4

. . . ROAD SPEED

A voltage signal proportional to car speed is required for computing operations and also for electrically indicating this speed on the instrument panel. The signal is developed by a direct current tachometer generator coupled to the usual speedometer takeoff pinion on the transmission. The tachometer puts out about 7 v at a road speed of 60 mph. This voltage amplitude is enough to operate computer circuits without further amplification. Also, low internal tachometer resistance permits a linear relationship between voltage and speed under a relatively large and varying instrument load.

A dc microammeter, connected as a dc voltmeter, measures the tachometer output voltage and indicates this in miles per hour.

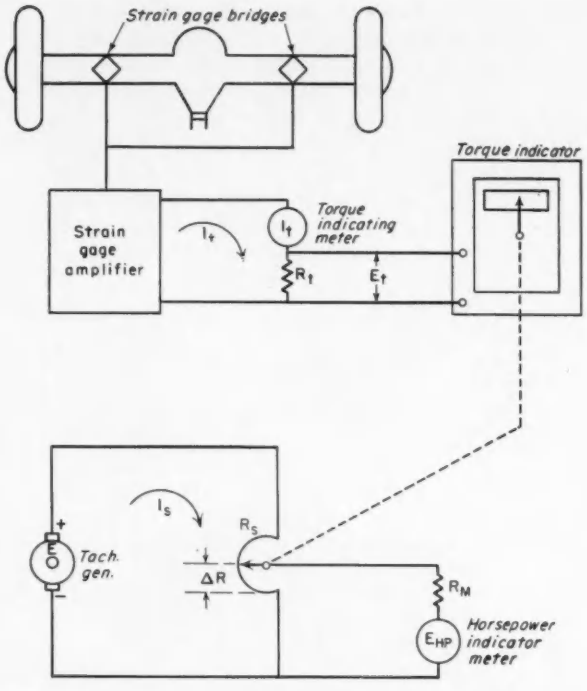
. . . MILES PER GALLON

Fuel economy in miles per gallon is obtained from an analog computer circuit which computes the ratio of road speed in miles per hour to fuel consumption in gallons per hour. The computer circuit, an Ohm's Law divider[3], appears in simplified form in Figure 4A. Its operation is based upon the analogy between the fundamental electrical relationship, $I=E/R$ and the relationship between the variables involved in fuel economy:

$$Miles\ per\ Gallon = \frac{Miles\ per\ Hour}{Gallons\ per\ Hour}$$

It is obvious that ammeter current, I, will be proportional to miles per gallon if the generator voltage, E, in the circuit is made proportional to miles per hour, and the resistance, R, is made proportional to gallons per hour.

Figure 4B is a schematic diagram of the complete computing system. The primary sensing device for measuring fuel flow is a Schutte-Koerting rotameter. The rotameter tube connects in the line carrying fuel to the carburetor so that its float assumes a vertical position proportional to flow rate. A slender rod connected to the bottom of the float extends down into the rotameter base and positions a core common to two coils located in the base. These coils form adjacent arms of a Wheatstone Bridge. Thus, float action moves the core along its longitudinal axis which increases the inductance of one



Servo driven potentiometer computes road horsepower. Fig. 5

coil and decreases that of the other, resulting in an unbalance in the Wheatstone Bridge. The unbalance signal goes to a Foxboro null-balancing flow indicator. The indicator thus follows float motion and provides a remote indication of the full flow rate. The arm of the computing potentiometer also is positioned by the flow indicator to make resistance, ΔR, proportional to the fuel flow rate.

The source of current for the circuit is the road speed tachometer, its internal resistance being represented by R_g. The miles per gallon indicating meter is a microammeter with an internal resistance, R_m. Hence the equation for current flow in this circuit is:

$$I = \frac{E_{gen}}{R_g + R_M + \Delta R}$$

It is evident that the minimum value for the denominator is limited by the constant resistances, R_g and R_m. In computing miles per gallon, this limitation makes it impossible to represent a region of fuel flow values below a certain minimum by a variable resistance. So it is necessary to adjust the ohms per gallon per hour factor of the computer to keep fuel flow represented by these constant resistances below any rate that occurs during road testing. With this adjustment, the computer equation is valid for flow rates above the fixed minimum. The current, I, is indicated as miles per gallon on a dc microammeter.

. . . HORSEPOWER

The horsepower developed at the rear wheels of the car can be computed from the following equation,

Horsepower $= K_1$ (Road Speed) (Axle Torque), where K_1 is a proportionality factor relating the speed-torque product to horsepower. This product can be computed electrically by means of the Ohm's Law relationship, $E = IR$[4]. If current, I, is proportional to road speed and resistance, R, is proportional to axle torque, then voltage, E, is proportional to horsepower because of the analogy between the Ohm's Law equation and the above horsepower equation. Figure 5 shows the basic horsepower computer circuit schematically.

The resistance, ΔR, in the circuit is made proportional to axle torque by positioning the sliding contact arm of potentiometer, R_s, proportionally to current, I_t, which flows in the torque indicating microammeter. The torque current flows through the pickup resistor, R_t, producing a millivoltage, E_t, proportional to the current developed across the resistor terminals. This millivoltage is the input to a Bristol "Dynamaster" recorder. Thus the recorder pen position becomes an indication of the axle torque. A special retransmitting slidewire potentiometer, R_s, couples directly to the positioning shaft of the recorder causing the resistance, ΔR, between its contactor and one end terminal, to be proportional to the input millivoltage; hence, to torque.

The outer terminals of R_s connect directly across the output terminals of the road speed tachometer. Hence the current I_s, that flows in the circuit, is directly proportional to car speed. The voltage, E_{hp}, developed across the variable resistance, ΔR, is given by the equation

$$E_{hp} = I_t \Delta R.$$

Since I_t is proportional to road speed and ΔR is proportional to axle torque, the voltage, E_{hp}, is proportional to horsepower.

The foregoing conclusion is based on the assumption that E_{hp} is an open circuit voltage. However, it is still necessary to indicate its value on the horsepower indicating microammeter. To avoid errors due to instrument loading, it is important that resistance, R_m, of the meter circuit be high with respect to the slidewire resistance, R_s. It is possible, with a careful choice of circuit parameters, to keep this loading error within one per cent. A dc microammeter, connected as a voltmeter, indicates the voltage, E_{hp}, in terms of horsepower.

. . . ENGINE SPEED AND SPARK ADVANCE

Two important variables which must be measured for engine and fuel test work are (1) the crankshaft speed of the engine in revolutions per minute, and

(2) the point in the cycle where fuel charge is ignited by the electrical ignition system. This latter variable is expressed in "degrees before top center"; that is, the number of crankshaft degrees ahead of the point where the piston reaches the top of its compression stroke. The distributors of modern ignition systems have automatic devices that cause the spark advance to vary with both engine speed and intake manifold vacuum to obtain optimum engine performance under different operating conditions. The total spark advance for any given condition is the sum of two settings. These are (1) the "basic" setting that is made with the engine running at its normal idling speed, and (2) the automatic setting that is determined by engine speed and vacuum control devices. The Cadillac "75" has two spark advance indicating meters; one to show the basic setting and the other, the total setting.

The basic spark setting is made by rotating the distributor housing and changing the relative positions of the cam follower and the cam which actuates the ignition breaker points. The position of the distributor housing is, therefore, directly proportional to the basic spark setting. An electrical indication of spark advance is obtained from a positioning circuit which is essentially a slide-wire potentiometer with its contact arm positioned by the distributor housing.

To indicate total spark advance, a General Instruments and Engineering Co. spark protractor electronically measures time interval between spark and when the corresponding piston reaches its top center position. This protractor consists of a bistable multivibrator circuit triggered alternately by the spark and a magnetic pickup which signals each time a piston reaches the top. The multivibrator thus generates a continuous train of square pulses of durations proportional to the time interval of the spark advance. A microammeter located in the appropriate triode of the circuit indicates the direct current average of the conducting intervals of the tube. These average intervals are proportional to the average spark advance of the eight cylinders.

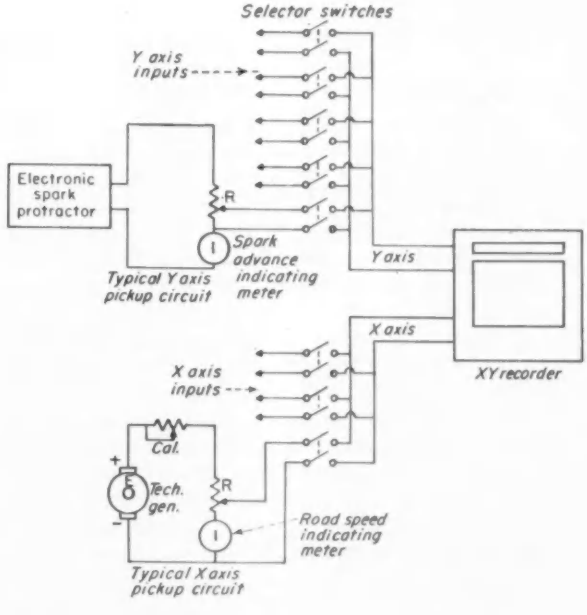
THE KEY INSTRUMENTS . . . FUNCTION PLOTTER

The function plotter is a Leeds and Northrup 'Speedomax" X-Y recorder requiring 20 mv at its input terminals for full scale deflection on either the "X" or "Y" axis. Its pen carriage is positioned by the"X" axis input signal and chart rolls are moved by the "Y" axis input signal. This produces a two coordinate plot of the two signals.

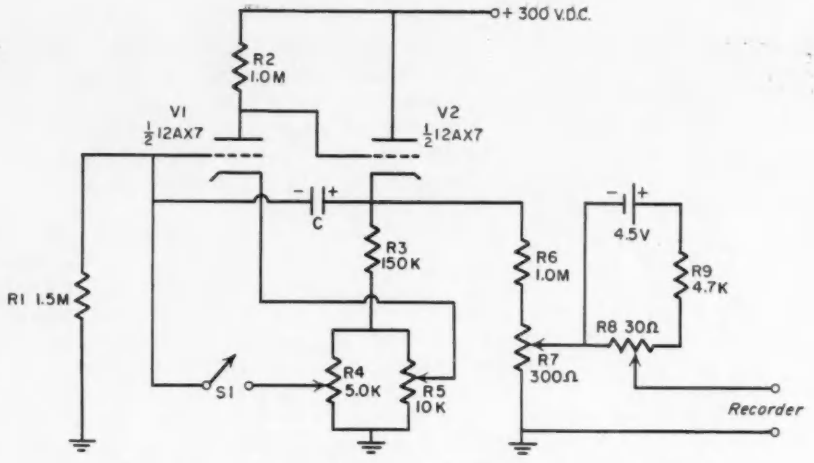
All instruments described thus far employ dc microammeters for output indications. Hence, a standard millivoltage pickup circuit can be used in series with each meter to provide input signals for the recorder. Simplified diagrams of these pickup circuits are shown schematically in Figure 6. The current flow in the indicating microammeter causes a proportional voltage drop across the pickup potentiometer, R, which is slightly greater than the voltage necessary to drive the recorder over full scale. The recorder scale is adjusted by setting the sliding contact accurately to correspond to the meter scale.

Pickup potentiometers in the meter circuits connect to input terminals of the recorder through push button selector switches. The operator thus can select any two desired variables for recording.

The following variables are routed to the X-Y



Push button switches permit operator selection of variables for X-Y recorder. Fig. 6



Miller integrator circuit furnishes time axis for X-Y recorder. Fig. 7

recorder input terminals by push button selection:

"X" Axis	"Y" Axis
1. Road Speed	1. Torque
2. Engine Speed	2. Road Speed
3. Time	3. Miles per Gal
	4. Horsepower
	5. Spark Advance

Combinations of inputs can thus produce desired plots of the following useful relationships:

1. Torque vs. Road Speed
2. Horsepower vs. Road Speed
3. Miles per Gal vs. Road Speed
4. Miles per Gal vs. Time
5. Road Speed vs. Time.
6. Spark Advance vs. Engine rpm

. . . X-AXIS SWEEP GENERATOR

An electronic sweep circuit augments the "X" axis of the recorder to make graphs which relate "Y" axis variables to time. The circuit, shown in Figure 7, provides the operator with switch selection of full scale sweep times of 20, 40, or 80 seconds. Output of the circuit or sweep generator is a millivoltage that rises linearly from zero to 20 mv in the selected sweep time.

The sweep generator is basically a Miller integrator with a regenerative feedback circuit for improving sweep linearity [5,6]. The plate of the Miller integrator tube, V_1, is directly coupled to the grid of cathode follower, V_2. The Miller feedback principle is obtained by returning the cathode follower output to the grid of V_1 through the sweep capacitor, C. Regenerative feedback is obtained by connecting the cathode of V_1 to ground through an adjustable tap on potentiometer, R_5, in the cathode follower load circuit. Hence the regeneration can be adjusted so that the system operates near infinite gain.

The sweep cycle is controlled by switch S_1 which is opened to initiate a sweep and closed to return the output voltage to its quiescent value. With S_1 closed the grid of V_1 connects to the adjustable tap on potentiometer R_4 in the cathode follower load circuit. This establishes the quiescent operating point of the circuit and stabilizes it through inverse feedback. The tap on R_4 adjusts this quiescent operating point for the most linear operating region of the circuit. Closing S_1 also allows the sweep capacitor, C, to discharge through the low output resistance of the cathode follower.

When S_1 is opened the plate voltage of V_1 rises linearly toward the plate supply voltage. The plate of V_1 is connected directly to the grid of V_2 and the output voltage is taken from the cathode of V_2. The range of the output voltage is from about 100 to 250 v. This voltage is reduced to the zero to 20 mv recorder range by the voltage divider circuit, R_6 and R_7, and the quiescent component is balanced to zero by the balancing circuit consisting of the battery, E, and the resistances, R_8 and R_9. The adjustment on R_8 serves as a calibration adjustment.

The sweep duration is directly proportional to the value of the sweep capacitor C. Sweep time, zero set, and sweep cycle controls are displayed.

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NOMENCLATURE:

p = air pressure
V = volume of air
W = weight of air
R = gas constant
T = absolute temperature
p_c = critical pressure at throat of nozzle
p_i = inlet pressure to nozzle or valve
A_t = area of nozzle throat
T_i = absolute temperature at input to nozzle
G = servo loop gain
S = frequency variable of Laplace transformation
K = constant
N = feedback factor
k_n = nozzle constant
A_v = area of valve
b_v = width of valve
Y = input motion (displacement of valve)
W_1, W_2 = weight of air in piston chambers
V_1, V_2 = piston chamber volumes
T_0 = assumed constant absolute temperature
p_1, p_2 = piston chamber pressures
A = effective area of piston
F = force acting on piston
W_0 = total weight of air trapped in both piston chambers
x = piston displacement to right
M = effective mass of load and piston measured at piston rod
R_x = viscous load friction at piston rod
K_s = spring constant of load at piston rod
D = velocity constant of servo motor
ξ = damping ratio of quadratic factor
L = length of restrictive tube
μ = viscosity of fluid
A_r = cross-sectional area of tube
ρ = density of fluid
k = constant
p_{c1}, p_{c2} = pressures in stabilization chambers
W_{c1}, W_{c2} = weight of air in stabiliztion chambers
V_{c1}, V_{c2} = volume of stabilization chambers
K_{r1}, K_{r2} = constants of stabilization restrictions
Ω_0 = characteristic natural frequency of servo motor
δ = characteristic damping coefficient
n, t, γ, τ = as defined in text

TIE SIMPLICITY TO POWER WITH

Pneumatic Servomechanisms

Here is a larger, broader future for pneumatics in control. Going back to basic gas law, this article derives the transfer function and suggests an unusual stabilizing technique for a linear pneumatic motor. Conclusion: good design insures high dynamic performance at frequencies of 12 cps or better, even under sizable load.

HAROLD LEVENSTEIN, The W. L. Maxson Corp.

SOME PNEUMATICS BACKGROUND The basic relation in a pneumatic servomechanism is the gas law. For a perfect gas, the relationship between pressure, p, volume, V, weight, W, and temperature, T, can be expressed

$$pV = WRT \tag{1}$$

The constant R is the gas constant; its units are chosen to make Equation 1 dimensionally correct.

Another relationship is also necessary. Air is admitted to the working chamber of the servo through a valve. This valve is treated as a nozzle. When the final nozzle output is less than a critical pressure, p_c, flow is at maximum and stays constant for all final pressures less than p_c. The critical pressure is about half the inlet pressure.

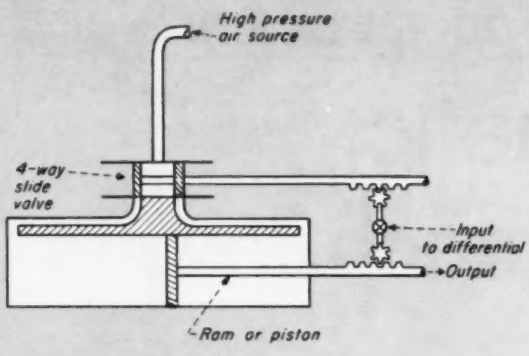
$$p_c = 0.53 p_i \tag{2}$$

In this analysis, the final pressure will not increase greatly above p_c, and the air flow is derived by

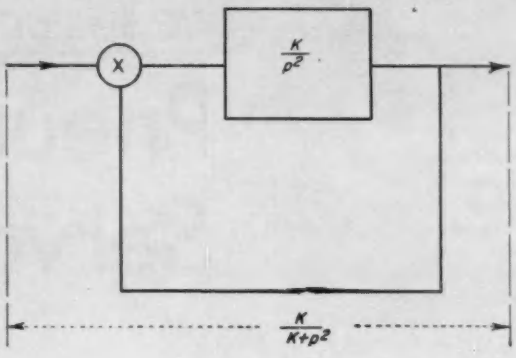
$$W = \frac{0.532 A_t p_i}{T_i^{1/2}} \text{ lbs/sec} \tag{3}$$

Hence the important relationship is the linearity between W, the rate of flow, and A_t, the area of the nozzle.

To date, pneumatic devices have not been used for high-powered, high dynamic performance industrial control. But it now appears that they may fill a vital gap between low-powered electrical servos and high-powered hydraulic systems.



Elementary air motor includes mechanical feedback between input or valve position and output or piston position. FIG. 1



Closed loop functional diagram for elementary air motor. FIG. 2

Pneumatic systems offer certain advantages over the better-established techniques. For one, high pressure oil leakage problems are eliminated. For another, the structure of pneumatic systems is simple. Reservoirs are unnecesary and weight can be reduced. However, there is at least one difficulty — keeping the moving parts of pneumatic systems lubricated. But when a plant has compressed air readily available, serious consideration should be given to pneumatic methods of performing servo operations.

The Servo Unit

The servo's motor element is a conventional valve and cylinder structure. Air is ported to one side of the cylinder and vented from the other to atmosphere, producing a force on the piston face.

Servo characteristics are obtained by feedback from the output to the controlling valve, Figure 1. Assume that the valve covers the two ports and that the piston is stationary at the center of its chamber. A displacement of the input member transmitted through the differential opens the valve and jets high pressure air into the piston chamber. If the valve moves to the left, the left port opens and air forces the piston to the right. Air trapped in the right piston chamber vents to atmosphere through the uncovered right port.

Piston motion is fed back to the valve through the differential. The piston thus moves until the ports close and the valve and piston are stationary. Hence the movement distance is determined by the valve input, and the servo is a position follow-up mechanism. If load does not exceed total available force on the face of the piston, the scale of follow-up is determined by the feedback ratio.

However, there is some doubt about the dynamic stability and fidelity of the pneumatic servo:

▶ Will it find a stable position?

▶ How well will it reproduce the input signals?

Before considering the mathematical aspects of the problem, some physical feeling for the behavior of the system must be established.

Opening the valve causes a flow of air to the cylinder chamber and produces a force on the face of the piston. By regarding the piston as inertia only, it is observed that an acceleration results. Thus the transfer function, G, between valve displacement and piston displacement is approximately

$$G = \frac{K}{S^2} \tag{4}$$

This deliberately ignores many pertinent factors that modify the relationship. The most serious of these, influence of the load and rate of air input, will be considered later.

Figure 2 represents the functional feedback diagram. The servo loop has a forward transmission K/S^2, a feedback transmission, N, and and overall transmission function G where

$$G = \frac{output}{input} = \frac{K}{S^2 + NK} \tag{5}$$

Superficially, the system appears neutrally stable. This is due to lag of the piston mass as it trys to respond to feedback commands to the valve. In responding, the piston overshoots and calls for a reverse control action where it again overshoots (but not promptly).

At this point, it seems there may be a problem of stability. But damping, load and valve characteristics, and mechanical networks in the feedback loop could modify this appreciably. Hence the dynamic behavior must be formulated with considerably more rigor.

Analysis of Basic Servo

The first step is to develop a transfer function

for the relationship between piston displacement and valve displacement. Only small motions of the piston and valve about their center positions will be considered. The actual air processes taking place—the nature of expansion and flow of the air —will not be examined. This is a convenient approach and leads to a useful mathematical description of the system.

Displacing the valve slightly from its closed position lets air into the chamber at a rate

$$\frac{dW}{dt} = k_n A_n \tag{6}$$

Nozzle area is considered proportional to valve displacement.

$$A_n = b_n Y \tag{7}$$

Therefore

$$\frac{dW}{dt} = k_n b_n Y \tag{8}$$

The rate of air flow into the chamber is also proportional to valve displacement. Similarly, the rate of air exit from the vented side is proportional to valve displacement. Labeling the left and right sides of piston and valve 1 and 2 respectively,

$$\frac{dW_1}{dt} = k_{n1} b_n Y \tag{9}$$

$$\frac{dW_2}{dt} = k_{n2} b_n Y$$

The values of k_{n1} and k_{n2} depend on the source pressures. When Y is positive, k_{n1} is large since air is entering the chamber from the high pressure source. When Y is negative, k_{n1} is smaller since it represents the rate at which air flows from the venting side of the piston. k_{n2} is negative and has magnitudes complementary to k_{n1} for Y positive and negative.

The second necessary relationship is the gas law. Air flows in one side of the chamber and out the other. The force developed across the piston face can be calculated from this. Consider the left hand side of the chamber filling with air.

$$p_1 V_1 = W_1 R T_1 \tag{10}$$

The variables are P_1, V_1 (from piston motion), W_1 and T_1. For convenience assume that T_1 and T_2 are constant and equal to T.

The pressure difference across the piston is

$$P = p_1 - p_2 = \frac{W_1 R T}{V_1} - \frac{W_2 R T}{V_2} \tag{11}$$

and the force acting on the piston is

$$F = A P = A R T \left[\frac{W_1}{V_1} - \frac{W_2}{V_2} \right] \tag{12}$$

At dynamic equilibrium, all load forces will be equated to F. Equation 12 contains W_1 and W_2 but not their rates of change. By differentiating this equation with respect to time

$$\frac{dF}{dt} = A R T \left[\frac{dW_1/dt}{V_1} - \frac{dW_2/dt}{V_2} - \frac{W_1}{V_1^2}\frac{dV_1}{dt} + \frac{W_2}{V_2^2}\frac{dV_2}{dt} \right] \tag{13}$$

Since the behavior has been confined to small changes, V_1 is substantially equal to V_2. Also, the increment in V_2 is the negative of the increment in V_1. Using these relations and collecting terms, the following expression is obtained.

$$\frac{dF}{dt} = A R T \left[\frac{1}{V_1} \left(\frac{dW_1}{dt} - \frac{dW_2}{dt} \right) - \frac{W_1 + W_2}{V_1^2} \frac{dV_1}{dt} \right] \tag{14}$$

In this equation W_1 and W_2 represent the air trapped in the piston chambers. For small fluctuations, W_1 and W_2 are substantially constant and thus their sum can be regarded as constant, W_o.

Since the chamber has a constant cross section, dV_1/dt can be replaced by Adx/dt where x is the displacement of the piston to the right.

$$\frac{dF}{dt} = \frac{A R T}{V} \left[\frac{dW_1}{dt} - \frac{dW_2}{dt} \right] - \frac{A^2 R T}{V_1^2} W_0 \frac{dx}{dt} \tag{15}$$

Introducing the load forces

$$F = M \frac{d^2x}{dt^2} + R_x \frac{dx}{dt} + K_s x \tag{16}$$

where M is the total mass of the load and piston, R_x is the viscous friction, and K_s is the spring constant, all measured at the piston rod. Differentiating Equation 16 with respect to time,

$$\frac{dF}{dt} = M \frac{d^3x}{dt^3} + R_x \frac{d^2x}{dt^2} + K_s \frac{dx}{dt} \tag{17}$$

and combining Equations 15 and 17, we get

$$M \frac{d^3x}{dt^3} + R_x \frac{d^2x}{dt^2} + K_s \frac{dx}{dt} = \frac{A R T}{V_1} \left[\frac{dW_1}{dt} - \frac{dW_2}{dt} \right] - \frac{A^2 R T}{V_1^2} W_0 \frac{dx}{dt} \tag{18}$$

Introducing the valve displacement from Equation 9

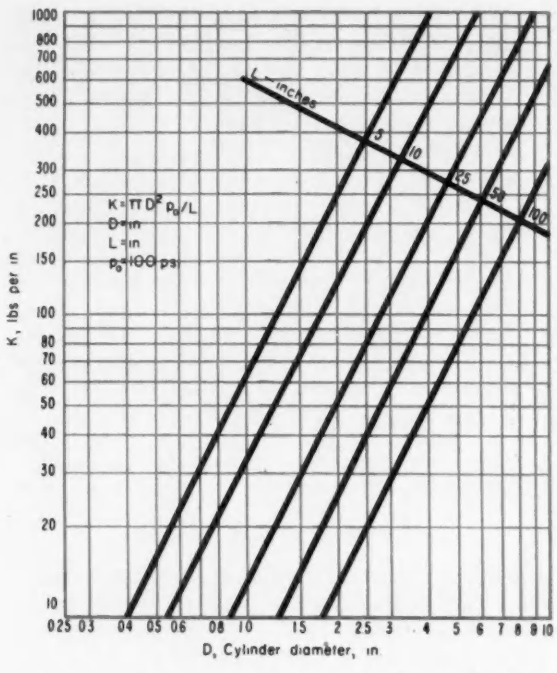
$$\frac{M d^3x}{dt^3} + \frac{R_x d^2x}{dt^2} + \left(K_s + \frac{A^2 R T}{V_1^2} W_0 \right) \frac{dx}{dt} = \frac{A R T}{V_1} b_n (k_{n1} - k_{n2}) Y \tag{19}$$

The term $(k_{n1}-k_{n2})$ is a constant under the conditions described and can be represented by k_n.

Without spring loads or friction, i.e., when the second and third terms of Equation 19 are zero, the piston mass responds as the third integral of valve displacement. This departure from the earlier assumption made in Equation 4 results from the gradual increase in air pressure as the valve is opened. Equation 4 asumes a step increase.

Note that the air trapped in the chambers, W_o, behaves like a spring and is grouped with the load spring constant in the equation. To some, the spring rates of trapped compressed air come as a surprise. Figure 3 shows the spring coefficients of typical piston-chamber combinations.

Note also that there is no friction term resulting from the air properties. R_x is composed of load friction and friction incidental to the mechanical structure of the piston and its chamber. Since the latter is a poor source of friction when well designed,



Spring coefficients of typical piston-chamber combinations.
FIG. 3

the load itself is heavily relied on for stabilization.

To discuss the system conventionally, introduce the operator S and write the input-output ratio. Then the transfer function of the motor is

$$\frac{X(S)}{Y(S)} = \frac{\frac{ARTb_nk_n}{V_1}}{S\left(MS^2 + R_xS + K_s + \frac{A^2RTW_0}{V_1^2}\right)} \qquad (20)$$

To appreciate the magnitudes of these literal quantities, consider the accompanying example. This evaluates the various terms of the transfer function for a representative motor. For the selected parameters, with a piston of very large mass, the motor has a natural frequency of approximately 12 cps. This can reach 30 to 50 cps through judicious selection of chamber proportions and air pressure.

The low-frequency behavior of the motor is that of a simple integrator. The spring terms arising in the load and the untrapped air assure this. But addition of the spring load reduces gain.

If spring load is considered zero, servo gains can be compared. Define quantity D by the following.

$$D = \frac{\left(\frac{ARTb_nk_n}{V_1}\right)}{\left(\frac{A^2RT}{V_1^2}W_0\right)} \qquad (21)$$

A SAMPLE DESIGN

PARAMETERS:

M = piston and load mass = 1 slug ft²

K_s = spring load = 0

p_0 = source pressure = 200 psi

b_n = valve width = 0.01 ft

T = absolute temperature = 530 deg R

CALCULATIONS:

$$V = V_1 = \frac{\pi(3)^2 12}{1{,}728} = 0.196 \text{ ft}^3$$

$$A = \pi r^2 = 0.196 \text{ ft}^2$$

$$W_0 = W_1 + W_2 = 2\,\frac{\frac{p_0}{2}}{RT}\,V = 2 \times 10^{-1} \text{ lbs}$$

$$\frac{A^2RT}{V_1^2}\,W_0 = 5.65 \times 10^{-3} \text{ lb/ft}$$

$$k_n = \frac{0.532}{T_1^{1/2}}\,p_0\,\frac{3}{2} = 10^3 \text{ lbs/sec}$$

$$\frac{ART}{V_1^2}\,k_nb_n = 1.44 \times 10^6 \text{ lb/sec/ft}$$

$$\frac{X}{Y} = \frac{\frac{ART}{V_1^2}\,k_nb_n}{S\left(MS^2 + R_xS + \frac{A^2RT}{V_1^2}\,W_0\right)}$$

$$\frac{X}{Y} = \frac{1.44 \times 10^6}{S(S^2 + R_xS + 5.65 \times 10^3)}$$

$$\Omega_0 = \sqrt{5.65 \times 10^3} = 75.1 \text{ rad/sec} \cong 12 \text{ cps}$$

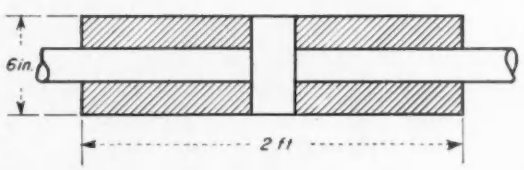
With feedback ratio N, criterion of absolute stability is

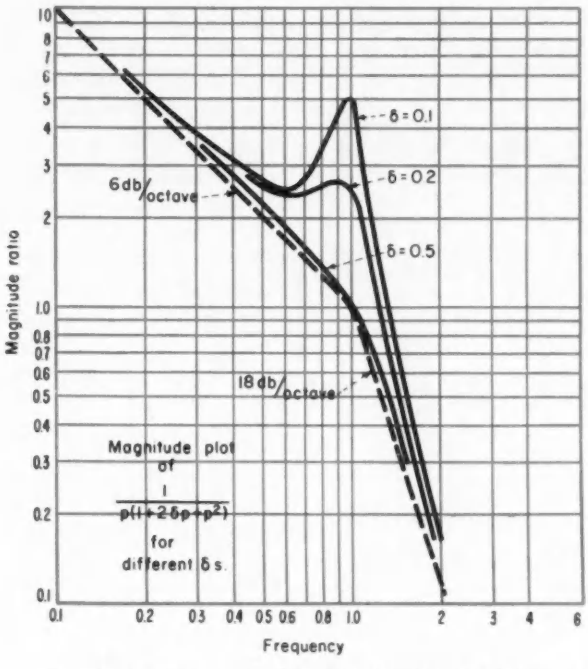
$$R_x \gg N\,\frac{1.44 \times 10^6}{5.65 \times 10^3} \gg (2.55 \times 10^2)\,N \text{ lb/ft/sec}$$

For a feedback ratio of $N = 10^{-1}$

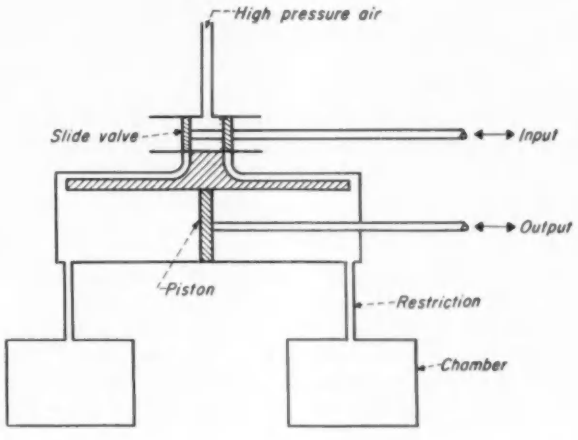
$$R_x \gg 25.5 \text{ lb/ft/sec}$$

And for 6 db of gain margin, $R_x = 51$ lb/ft/sec





Transfer function expressed by Equation 20 plotted for various values of the damping ratio of the quadratic factor. FIG. 4



In modified servo motor stabilization chambers connect to piston chambers through restrictive passages. FIG. 5

By evaluating W_o and k_n from their definitions and the relations that have been established, and assuming that cylinder pressure is about one-half source pressure, it can be shown that

$$D \leqq 3\,\frac{Rb_n T^{1/2}}{A} \tag{22}$$

The significant relationship here is that the *gain of the servo motor, considered in its integrator mode, depends only on the ratio of the width of the valve port to the cross-sectional area of the piston.* Enough assumptions have been made to question the constant 3 in Equation 22, but this does not effect the above statement. Note that the source pressure has disappeared from the gain. It will reappear when spring load is significant as compared to trapped air.

Figure 4 shows the transfer function plotted for various values of a quantity ξ using normalized scales. The damping ratio of the quadratic factor is defined below:

$$\xi = \tfrac{1}{2}\,\frac{R_x}{\sqrt{M\left(K_s + \dfrac{A^2RTW_0}{V_1^2}\right)}} \tag{23}$$

As R_x (and ξ) become small, the function peaks sharply. This is important for system stability.

Closing the loop mechanically with a solid feedback connection N (N units of valve displacement per unit piston displacement) completes the formulation of the servo problem. The loop gain is

$$LG = \frac{N\left(\dfrac{ARTb_nk_n}{V_1}\right)}{S\left(MS^2 + R_xS + K_s + \dfrac{A^2RTW_0}{V_1^2}\right)} \tag{24}$$

The characteristic algebraic equation whose roots specify the stable character of the servo is

$$CAE = MS^3 + R_xS^2 + \left(K_s + \frac{A^2RTW_0}{V_1^2}\right)S + N\left(\frac{ARTb_nk_n}{V_1}\right) \tag{25}$$

By Routh's method, it can be shown that the following must be true for absolute stability.

$$R_x\left(K_s + \frac{A^2RTW_0}{V_1^2}\right) \gg MN\,\frac{ARTb_nk_n}{V_1} \tag{26}$$

Friction prevents destructive vibration.

Improving Stabilization

It is unsafe to rely on incidental friction in the load and the servo motor. Changes in temperature or lubrication can seriously affect performance. Other methods are preferred for improving stability. One of the most obvious is adding a damper to insure sufficient dissipation. Its minimum force coefficient can be calculated from Equation 26.

More sophisticated methods should be considered. While it is possible to modify the feedback link

by introducing mechanical and pneumatic networks, the method examined here involves altering the forward transfer function. This requires some structural changes in the servo motor.

Figure 5 shows the modified servo motor. Each piston chamber is connected to a second chamber through a restriction. Pressures in these storage chambers are substantially the same as those in the piston chambers, so that small pressure differences exist across the restrictions.

Under these circumstances, the flow through the restriction will be viscous laminar. The relationship between flow and pressure difference is linear.

$$\Delta p = \frac{kL\mu}{A_r \rho} \frac{dW}{dt} \tag{27}$$

The variables are L, the length of the restrictive tube, A_r, the cross-sectional area of the tube, ρ, the density of the air and μ, the viscosity of the fluid where k is a constant with appropriate units. This equation is a variation of Poisenille's formula for viscous flow. Equation 15 stated that

$$\frac{dF}{dt} = \frac{ART}{V_1}\left[\frac{dW_1}{dt} - \frac{dW_2}{dt}\right] - \frac{A^2RT}{V_1^2} W_0 \frac{dx}{dt} \tag{15}$$

In the new motor the quantities W_1 and W_2 are affected not only by the valve and piston performance, but also by the reaction of the restriction and chamber combination. As the piston chamber pressure fluctuates, air will be exchanged between the storage chamber and the piston chamber.

$$\frac{dW_1}{dt} = [\text{air input from valve}] - \frac{dW_{c1}}{dt} \tag{28}$$

The following equations hold for the restriction-chamber combination.

$$p_{c1} = W_{c1} \frac{RT}{V_{c1}} \tag{29}$$

$$p_{c1} - p_1 = -K_{r1} \frac{dW_{c1}}{dt} \tag{30}$$

Combining Equations 29 and 30 yields

$$p_1 = W_{c1}\left(\frac{RT}{V_{c1}}\right) + K_{r1} \frac{dW_{c1}}{dt} \tag{31}$$

Using the analogy between pressure and voltage, and air flow and current, Equation 31 is recognizable as the differential equation of a resistance and capacitance in series. In operational notation 31 becomes

$$W_{c1} = \frac{1}{\left(\frac{RT}{V_{c1}}\right) + SK_{r1}} p_1 \tag{32}$$

$$\text{and similarly } W_{c2} = \frac{1}{\left(\frac{RT}{V_{c2}}\right) + SK_{r2}} p_2 \tag{33}$$

Combining Equations 32 and 33 with 15 in operational notation and manipulating the relation yields

$$\frac{X}{Y} = \frac{\frac{ART}{V_1} k_n b_n}{S\left[\left(1 + \frac{RT/V_1}{RT/V_c + K_r S}\right)(MS^2 + R_x S + K_s) + \frac{A^2RT}{V_1^2} W_0\right]} \tag{34}$$

This can be made simpler and easier to understand by introducing some new notation. As reference conditions, consider the servo without spring load or compensation. The motor will have a characteristic natural frequency Ω_0 caused by inertia and air spring where:

$$\Omega_0^2 = \frac{1}{M} \frac{A^2RT}{V_1^2} W_0 \tag{35}$$

There will be a characteristic damping coefficient δ, where:

$$\delta = \frac{1}{2} \frac{R_x}{M} \frac{1}{\Omega_0} \tag{36}$$

The velocity constant (or gain in the integrator mode) G, is given by

$$G\Omega_0^2 = \frac{1}{M} \frac{ART}{V_1} k_n b_n \tag{37}$$

In addition let $\gamma = \frac{V_c}{V}$ and $\tau = K_r \frac{V_c}{RT}$

These can be substituted in Equation 34 to give

$$\frac{X}{Y} = \frac{G\Omega_0^2}{S\left[\left(1 + \frac{\gamma}{1 + \tau S}\right)(S^2 + 2\delta\Omega_0 S + K_s\Omega_0^2) + \Omega_0^2\right]} \tag{38}$$

Finally change the time scale of the variable so that

$$S = \Omega_0 u \text{ and } \tau = \frac{t}{\Omega_0} \text{ then}$$

$$\frac{X}{Y} = \frac{G/\Omega_0}{u\left[\left(1 + \frac{\gamma}{1 + ut}\right)(u^2 + 2\delta u + K_s) + 1\right]} \tag{39}$$

While numerical exploration of the system is possible, a quicker demonstration of the improvement in stability can be made.

Let K_s equal zero (no spring load). Then the denominator can be written as

$$u\left[u\left(\frac{1 + \gamma + ut}{1 + ut}\right)(u + 2\delta) + 1\right]$$

Selecting t so that the $(1+ut)$ term cancels the $(u+2\delta)$ term, effectively replaces $(u+2\delta)$ with $(u+\gamma+ut)$. To do this t is chosen to be $(2\delta)^{-1}$ and the denominator becomes

$$u\left\{u[u + (1 + \gamma)2\delta] + 1\right\}$$

The dissipation coefficient δ has been multiplied by $(1+\gamma)$ which is in the right direction for improved stability.

Note that for large increases in effective damping, γ must be large. That is, the external chambers must be several times larger than the piston chambers. This method of stabilization is particularly effective where space is not at a premium.

SELECTED REFERENCE

J. L. Shearer, *CONTINUOUS CONTROL OF MOTION WITH COMPRESSED AIR*, M.I.T. Dept. of Mech. Eng., ScD thesis, Cambridge, Mass., 1954.

How Temperature Compensation Can Be Used

The effects of temperature change on instrument accuracy and five ways to compensate for these effects were covered in the April and May issues of CONTROL ENGINEERING. This final article adds two more compensating methods and shows how combinations of all the techniques apply in subduing effects of temperature in five commercially available components.

ROBERT GITLIN, Servomechanisms, Inc.

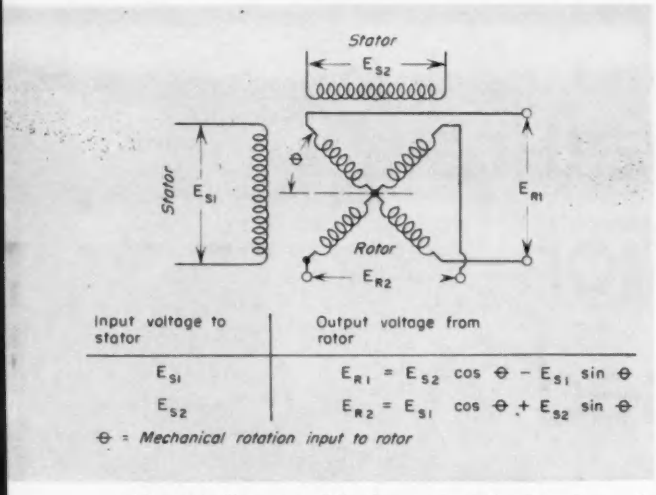
Like mechanical elements, electrical components are also subject to inaccuracies due to changes in ambient temperature. One way to compensate for this temperature error is to add special windings as in compensating induction resolvers.

The induction resolver is essentially a rotary transformer with variable coupling between the primary and secondary windings. The windings are distributed to produce a true sinusoidal relationship between the output voltage and the angle of rotation of the rotor. Figure 1 shows this relationship.

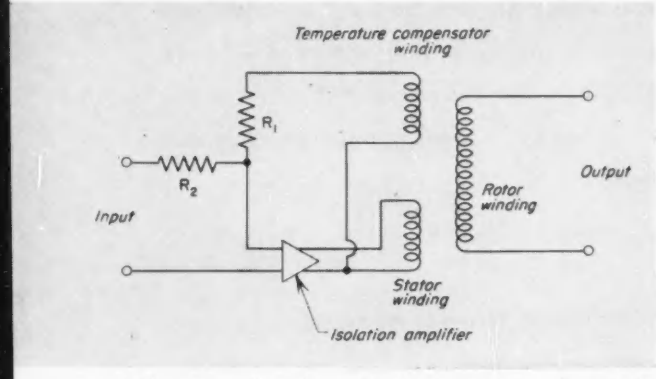
In an uncompensated resolver, temperature variations change the resistance of the copper windings. This produces two effects: a phase shift (zero scale error) and a variation in the transformation ratio (scale error).

In a typical Reeves compensated resolver, this difficulty is overcome by adding an auxiliary winding similar to the stator winding. This auxiliary winding is also inserted in the stator slots. The output voltage from this compensating winding is very nearly in phase with the rotor output voltage. It remains in phase despite changes in temperature since the effect of resistance changes (copper losses) is equal in both the compensating and rotor windings. In practice the compensating winding supplies a feedback voltage to a resolver isolation amplifier. Figure 2 shows a typical circuit.

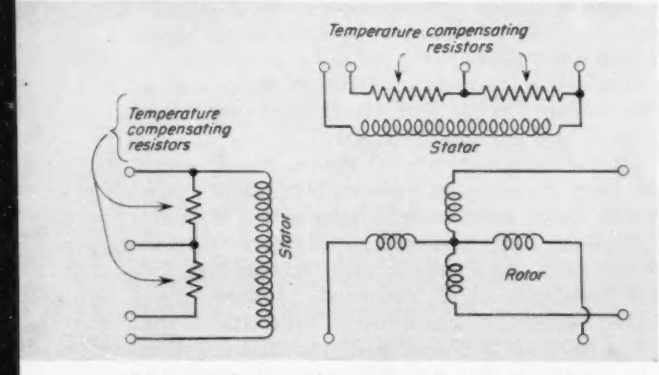
The summing resistors R_1 and R_2 supply unity gain from the amplifier input to the resolver rotor output. Since variation with temperature is nearly identical in the compensator and rotor voltages, the feedback loop automatically compensates for these variations. Tests on several resolvers using winding compensation indicate that the ratio of the voltage delivered by the rotor at maximum coupling varies about plus or minus 0.05 per cent. Also, the electrical phase shift is constant within one minute



Schematic diagram and fundamental relationships for an induction resolver. Rotor output voltages are expressed as a function of the stator input voltages and the angle of rotation of the rotor. FIG. 1



Induction resolver circuit showing temperature compensating windings. FIG. 2



Schematic diagram of typical standard resolver with built-in temperature compensating resistors. FIG. 3

over the temperature range from minus 55 to plus 85 C.

In resolvers without compensating windings, the effects of temperature variation can be minimized by positive current feedback in the amplifier that drives the resolver. To obtain temperature compensation, the current feedback voltage resistor must have the same temperature coefficient as the copper wire used in the resolver stator. The positive current feedback effectively produces a negative amplifier output resistance equal to the resolver copper resistance. Standard resolvers are available with the current feedback resistor built into the unit. Figure 3 shows a typical arrangement.

Regulating Ambient Temperature

Another way to prevent temperature errors in precision instruments is to hold the temperature range to prescribed limits or to maintain ambient temperature at a constant value. A heater and thermostat do this by preventing the temperature of the unit from dropping below a selected value. To be completely effective the thermostat is usually set at the highest temperature that the instrument will experience. But this means that the instrument must operate efficiently at this high temperature and that the system will suffer a continual power drain, since the heater will operate most of the time.

This technique has been used on a linear accelerometer. This unit has an unbonded strain gage as the pickoff and is critically damped with a silicone fluid. To maintain damping at a critical value over a temperature range of minus 65 to plus 120 F, the viscosity of the silicone must be kept constant. Since this viscosity varies somewhat with temperature, an electrical heater jacket and thermostat were added to maintain a constant ambient temperature of 135 F.

Equalizing Thermal Lags

In instruments where large temperature changes occur in relatively short periods of time (for example, in the rapid ascent or descent of an airplane), a compensator with a thermal lag different than the sensing element's will create a transient error instead of correcting it. Thus it is necessary to place the compensator as physically close to the sensing and transmitting elements as possible and to select a compensator with approximately the same thermal lag characteristic as the temperature sensitive primary elements.

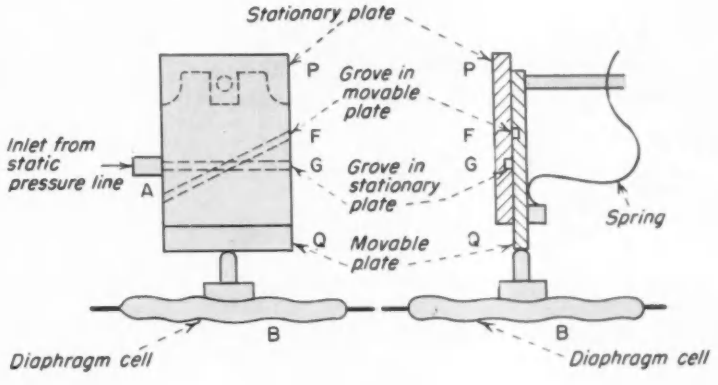
One way to do this is to match the product of compensator mass and thermal conductivity with that of the sensor to give the same relative thermal dissipation path. Another way is to vary the length of the compensator's heat dissipation path so that the compensator heats or cools at the same rate as the sensor.

Several more commonly used temperature com-

pensators were listed in the April and May issues of CONTROL ENGINEERING. These are by no means all, since any element that changes characteristics with temperature can be used as a temperature compensator. It's up to the instrument designer to select the compensator for a particular problem.

HOW IT'S BEING USED

To show how the compensating techniques discussed here and in the previous two articles have been used in commercially available instruments, several units are discussed in detail.



Temperature compensating technique used in rate-of-climb indicator. Changes in pressure in the diaphragm cell caused by changes in temperature result in motion of the movable plate and a change in capillary length. FIG. 4

RATE-OF-CLIMB INDICATOR

The typical rate of climb indicator in Figure 4 uses a partially filled diaphragm to correct for both altitude and temperature effects. The correction is obtained by varying the length of a capillary passage. The leak capillary passage is formed by a groove G engraved on a fixed flat plate *P* which is held next to a movable flat plate *Q*. A larger groove *F* is cut in the movable plate at an angle to groove G. Groove *F* is open to the chamber at both ends. Thus groove G forms a small channel of capillary size that extends from the edge of the plate, where the connection to the static pressure line *A* is made, to the point where the two grooves meet. The length of this channel can be varied by changing the position of the movable plate which bears against a diaphragm cell *B* filled with air under pressure.

A proper choice of cell pressure results in simultaneous temperature and altitude compensation. If the instrument temperature decreases, the pressure in auxiliary cell *B* decreases, the cell contracts and plate *Q* is moved to lengthen the capillary. This action compensates for the decrease in the viscosity of air with temperature. Similarly, an increase in altitude means a decrease in atmospheric pressure. Sealed cell *B* expands and moves plate *Q* to shorten the capillary. Correction results.

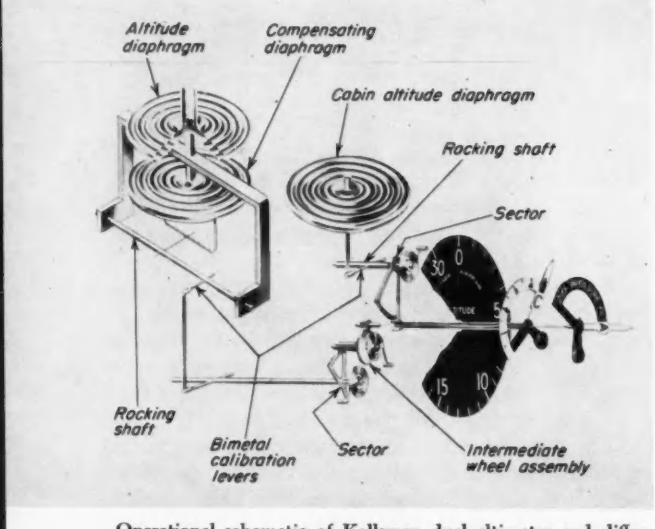
Exploded view of Servomechanisms, Inc., pressure transducer. Unit at left is twisted Bourdon tube of Ni-Span-C. Compensating thermistor and thermostat are mounted on spring clip. FIG. 5

A PRESSURE TRANSDUCER

A pressure transducer manufactured by Servomechanisms, Inc., consists of a pressure sensitive element in the form of a twisted torsion type Bourdon tube. One end of the tube connects to the armature of a four-pole magnetic-reluctance type pickoff. The Bourdon tube will twist an amount equal to the applied differential pressure. The unit can be made to detect atmospheric pressure by evacuating the tube and sealing it. Thus, the tube will twist an amount proportional to the static pressure introduced into the leak-proof chamber. Figure 5 shows an exploded view of this unit.

The electrical pickoff can sense motion in the order of 10 millionths of an inch. With this high sensitivity, it is necessary to make the transducer relatively insensitive to temperature to limit errors to about 0.1 per cent. Specifications dictate that the instrument maintain this accuracy over a temperature range of minus 55 to plus 70 C.

A heater and thermostat in the unit are set so that the temperature of the instrument will not fall below 0 C. This effectively narrows the temperature range over which the instrument has to operate accurately. Zero shift resulting from temperature effects on the magnetic pickoff is compensated for by a thermistor circuit. The Bourdon tube is of Ni-Span-C to maintain a constant shear modulus and thus give the same angle of twist for the same applied pressure over the reduced temperature range. The combination of these compensating techniques sufficiently subdue temperature effects to achieve desired performance.



Operational schematic of Kollsman dual altimeter and differential pressure gage. Temperature compensation is achieved by means of bimetal calibration levers. FIG. 6

DUAL ALTIMETER PRESSURE GAGE

The Kollsman dual altimeter and differential pressure gage is intended for use on aircraft having pressurized cabins. It expresses both cabin pressure and the atmospheric pressure in feet of pressure altitude. In this instrument, Figure 6, temperature compensation for both the external-barometric-pressure and the internal-cabin-pressure mechanisms is secured through a bimetal calibration lever attached to both rocking shafts. The bimetal calibration lever deflects with temperature, producing a compensating movement of the instrument pointers. This pointer motion is in a direction opposite to that produced by temperature changes in the diaphragm pressure-deflection characteristics (scale error) and in the differential expansion of the various linkages that result in zero shift. The calibration lever as used in this instrument effectively compensates for the zero shift temperature error.

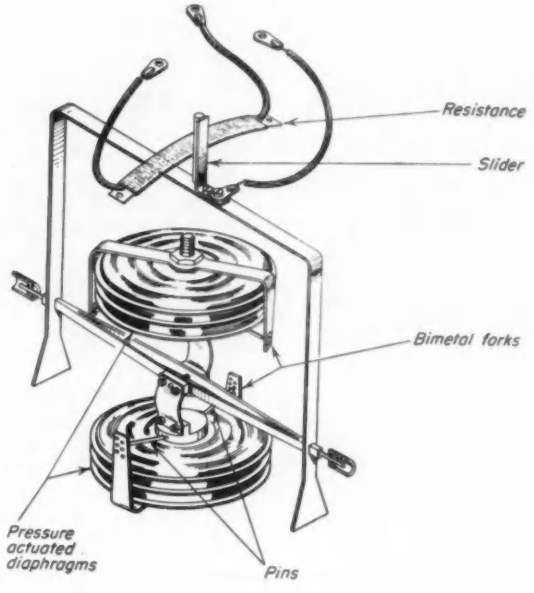
ABSOLUTE PRESSURE PICK-UP

Figure 7 is a schematic drawing of the Kollsman absolute pressure pickup. This unit gives an electrical output that is a function of absolute or differential pressure, airspeed, altitude and similar characteristics. Movement of the pressure actuated diaphragm turns the frame which in turn moves the slider across the resistance element.

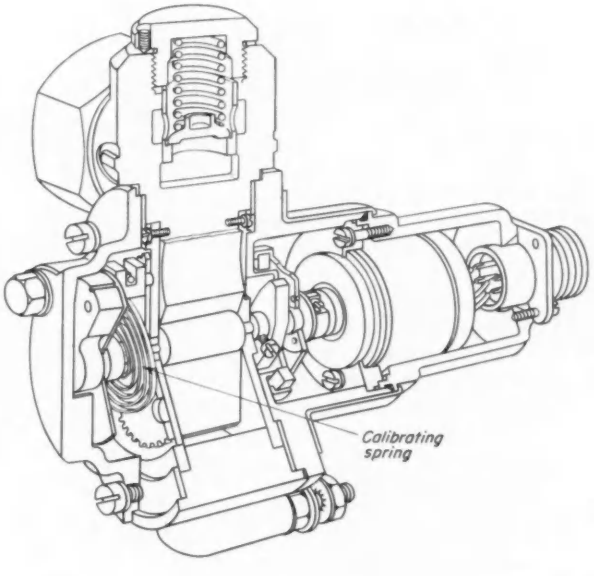
Temperature compensation occurs through the bimetal forks attached to the pressure sensitive diaphragms. Changes in temperature cause the arms of the forks to contract toward or expand away from the diaphragm axis. This motion is transmitted from the forks to the diaphragm by two pins. The movement of the bimetal forks results in

a movement of the wiper arm, thus compensating for zero shift errors in the pressure sensitive element and its linkages.

Any change through temperature in the spring rate of the restraining bimetal fork is compensated for by a change in the angle made by the two connecting pins with the diaphragms. This effects the pressure-deflection characteristics of the diaphragm assembly. Thus these characteristics remain essentially constant with changes in temperature, and scale error compensation is achieved. In this manner, the manufacturer accomplishes what is referred to as full-scale temperature compensation.



Schematic of Kollsman absolute pressure pickup. Bimetal forks, used for compensation, limit both zero shift error and scale error. FIG. 7



FUEL FLOW TRANSMITTER

The Eclipse-Pioneer aircraft fuel flow system consists of an Autosyn transmitter, Figure 8, mounted in the fuel supply line to the engine, and an indicator on the instrument panel. Fuel enters the inlet port of the transmitter and moves a vane against the restraining influence of a calibrated spring. The position of the vane, indicating the velocity of flow, is transmitted to the Autosyn rotor through a bar and ring magnet coupling. Specifications require accuracy tolerances over a range of minus 67 to plus 150 F. The calibration spring is of Iso-Elastic, a special alloy by John Chatillon and Sons that will hold its load-deflection ratio within one per cent over the specified operating range.

Cut-away view of Eclipse-Pioneer aircraft fuel flow unit using an Autosyn transmitter. Constant modulus spring material, Iso-Elastic, is used for the calibrating spring. FIG. 8

ACKNOWLEDGEMENT:

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These Steps Lead to Good Computers

CLIFFORD F. ABT, American Bosch Arma Corp., Arma Div.

THE GIST: Once a problem is clearly defined, final physical design of its computer proceeds by certain basic steps. Wide freedom of choice within this framework can result in several good designs for the same problem. But the basic steps must be followed.

This is especially true if the computer is regenerative; i.e., if it contains closed loops.

Take the problem of predicting the course and flying time for a tanker plane to intercept another plane for refueling. This requires a regenerative computer, even when confined to the azimuth plane for simplicity. The author follows the basic steps through an ac electromechanical instrumentation to solve this problem. And he illuminates each step by application.

Thus the principles and techniques described in four previous articles in this series are put to work in a realistic computer application. Down to the component level, alternatives are discussed where they are important. But the emphasis is always on the basic procedure.

The most common techniques in instrumenting an analog computer are mechanical, electromechanical, and electrical. Here the functional designer can apply the proper physical phenomenon that gives an analogous solution.

Electrical or electromechanical instrumentation divides into ac and dc types. The ac electromechanical technique is used here to demonstrate one typical approach to instrumentation.

THE STEPS

Once the problem has been clearly defined, these logical steps are followed:

1—Establish the specifications—input and output requirements, static and dynamic accuracy requirements, environmental conditions, and special considerations such as characteristics of available power supplies and integration with related equipment.

2—Derive the equations to be solved.

3—Instrument the equations on a simplified functional or block diagram basis.

4—Do an approximate error analysis to select specific computing elements and establish their order of accuracy.

5—Determine final instrumentation in detail—define electrical and mechanical scaling, compute circuit designs and servo designs, and compute element and servo performance specifications.

6—Do a detailed error analysis of the final instrumentation to assure adherence to performance specifications. At this point final accuracy and performance fixes can be made.

The location of the computer's input data source determines whether electrical scaled-voltage transmission or synchro transmission should be used. This article assumes close proximity and elects the less complex scaled-voltage transmission.

(Continued on Page 78)

THE METHOD APPLIED IN AN AIRBORNE REFUELING PROBLEM

Assume that one plane, the "target," must be refueled in flight from another plane, the "tanker." Contact must be made within range of a ground radar station without the target changing course or speed. A ground installed computer must use radar-supplied data to vector in the tanker on an intercept course, until the tanker's own radar can take over and complete the mission without further ground assistance. The rendezvous point should be continuously changeable to keep the target on schedule and to its flight plan.

For simplicity, assume that the target and tanker are flying at the same altitude and neglect these other real factors: computation of horizontal range and altitude; corrections of wind speed and course to compute tanker's compass heading and air speed; tanker rate of climb calculation.

COMPUTER SPECIFICATIONS

OUTPUTS:

The computer shall present numerically:

- C_T—tanker course
- T—time to fly to rendezvous point

INPUTS:

The ground control radar system shall supply these data as mechanical shaft positions:

- R—Range to target
- B—Bearing of target
- R_T—Range to tanker
- B_T—Bearing of tanker
- C—Target ground course
- S—Target ground speed

ALSO, A HAND SET INPUT:

- S_T—Tanker designated speed

AND SOME MISCELLANEOUS DEFINITIONS:

- D—Target distance to fly to rendezvous
- D_T—Tanker distance to fly to rendezvous

SOLUTION LIMITS:

The computer shall work within these limits:

- R—0 to 100 miles
- R_T—0 to 100 miles
- B—0 to 360°
- B_T—0 to 360°
- C—0 to 360°
- C_T—0 to 360°
- S—300 to 600 mph
- S_T—200 to 400 mph
- T—0.5 to 30 minutes
- D—150 miles (maximum)
- D_T—2 to 100 miles

ACCURACY:

The computer's probable maximum error in:

- C_T—shall not exceed an angular error equivalent to a distance across the tanker course of 0.5 mile or 2 per cent of tanker distance to fly, whichever is greater.
- T—shall not exceed 0.1 minute or 2 per cent of the tanker time to fly, whichever is greater.

THE GEOMETRY AND THE EQUATIONS

Figure 1 shows the geometry for the intercept prediction problem. The positions of the target P and tanker P_T are located relative to radar ground control station G by the respective ranges and bearings R, B and R_T, B_T. The target and tanker distances to fly to the rendezvous point O are D and D_T, and their corresponding courses, C and C_T. All bearings and courses are measured in degrees clockwise from true north. The problem's solution can be found within the shaded triangle defining tanker course C_T, and the distance to fly D_T.

The equations are written to produce the required outputs with the simplest instrumentation. Vector distances R, R_T, D and D_T must be resolved into their north and east components, whereupon all input functions can be used directly. The following four equations can be derived:

$$D_T \sin C_T = R \sin B - R_T \sin B_T - D \sin (C-180°) \quad (1)$$

$$D_T \cos C_T = R \cos B - R_T \cos B_T - D \cos (C-180°) \quad (2)$$

$$D = S\ T \quad (3)$$

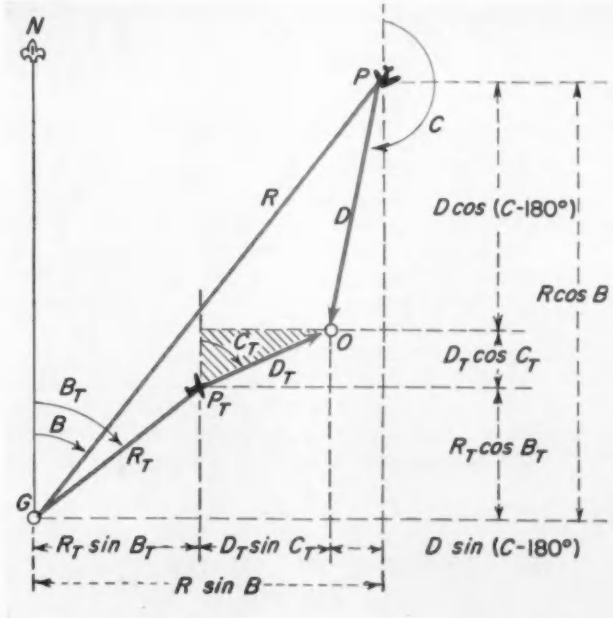
$$D_T = S_T\ T \quad (4)$$

which by combination and simplification yield

$$S_T\ T \sin C_T = R \sin B - R_T \sin B_T + S\ T \sin C \quad (5)$$

$$S_T\ T \cos C_T = R \cos B - R_T \cos B_T + S\ T \cos C \quad (6)$$

All terms in (5) and (6) are known except required outputs C_T and T. Note that T appears in terms on both sides of the equations, producing a closed-loop computer.



Computation can be done with equal facility at 60 or 400 cps. These are the commercially common frequencies for electromagnetic computing and servo components. The higher frequency is preferred where miniaturization is important. In general, however, frequency of available ac supply and computer size and weight restrictions decide.

Environment significantly affects the instrumentation. Large variations in temperature, for example, require more complex compensation circuits to maintain accuracy in certain computing elements—electromagnetic components in particular.

PRELIMINARY INSTRUMENTATION

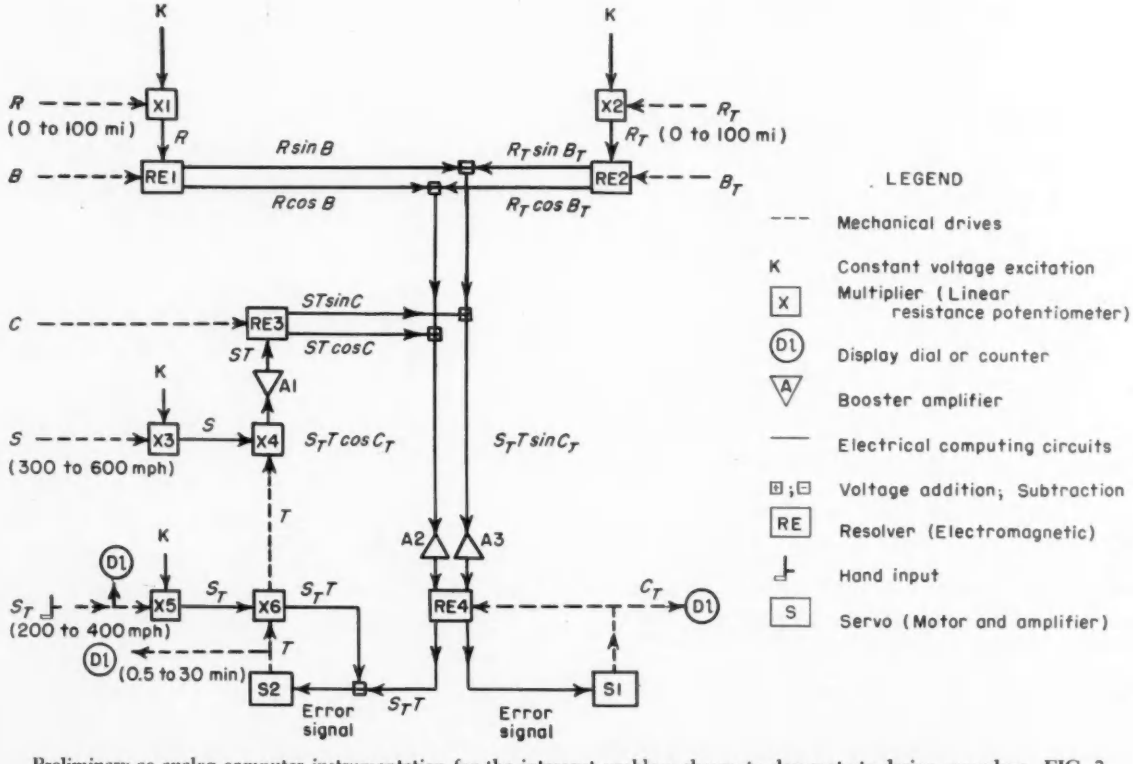
For early appraisal of the various instrumentations, the solution is roughed out in a simplified functional form. This facilitates investigation of the many possible approaches.

The preliminary instrumentation for the demonstration problem as developed from equations (5) and (6) is shown in Figure 2. The dashed lines represent mechanical shafts for the functions R, R_T, S, B, B_T and C in the radar ground control system. These are geared respectively to resistance potentiometers X1, X2, X3, and resolvers RE1, RE2, RE3. The arrows designate functional flow.

When potentiometer X1 is excited with a constant voltage, the output is a voltage proportional to target range R. If this voltage excites a primary coil on resolver RE1, driven by a shaft representing target bearing B, the output of the two resolver secondary coils is proportional to $R \cos B$ and $R \sin B$, which are the north and east components of the present target position relative to the ground control station. The north and east components of the present tanker position $R_T \cos B_T$ and $R_T \sin B_T$ similarly derive from potentiometer X2 and resolver RE2.

When potentiometer X3 is excited with a constant voltage, the output is a voltage proportional to target speed S. If this voltage excites another potentiometer X4, driven by the "time to fly" servo S2, then the output is proportional to S times T, or the target distance to the rendezvous point. If the output of potentiometer X4 excites one primary coil of resolver RE3, then the output of the two resolver secondary coils is proportional to the north and east components of target travel $S_T \cos C$ and $S_T \sin C$, respectively.

Summation of the outputs of resolvers RE1, RE2, and RE3 as per the signs in equations (5) and (6) gives $S_T T \cos C_T$ and $S_T T \sin C_T$, which are the north and east components of the tanker distance to fly to the rendezvous point. If these voltages excite the two primary coils of resolver RE4, then the output of one secondary coil is an error signal



Preliminary ac analog computer instrumentation for the intercept problem chosen to demonstrate design procedure. FIG. 2

TABLE 1

APPROXIMATE ERROR ANALYSIS FOR PRELIMINARY INSTRUMENTATION

COMPUTING ELEMENT				COMPUTING ELEMENT ERROR CONTRIBUTIONS (MILES)			
			FUNCTION	(4) Case #1	(5) Case #2	(6) Case #3	(7) Case #4
			R	100 mi	24 mi	24 mi	48 mi
			D	150 mi	30 mi	30 mi	6 mi
			B	270°	053°	053°	068°
			S	300 mph	300 mph	600 mph	600 mph
			C	083°	083°	083°	083°
(1)	(2)	(3)	R_T	100 mi	51 mi	51 mi	52 mi
		Magnitude of	D_T	100 mi	20 mi	20 mi	4 mi
	Assigned	Input or its	B_T	145°	092°	092°	074°
Element	Nominal	Contributing	S_T	200 mph	200 mph	400 mph	400 mph
Designation	Maximum	Equivalent	C_T	355°	355°	355°	355°
(See Fig. 2)	Error	in Miles	T	30 min	6 min	3 min	0.6 min
X1	0.20%*	100	Columns (4) to (7)	0.20	0.20	0.20	0.20
RE1	0.10%	R	are products of	0.10	0.03	0.03	0.05
X2	0.20%*	100	columns (2) and (3)	0.20	0.20	0.20	0.20
RE2	0.10%	R_T	for function	0.10	0.05	0.05	0.05
X3	0.30%**	10T	values in cases	0.90	0.18	0.09	0.02
RE3	0.25%	D	tabulated:	0.38	0.08	0.08	0.02
X4	0.05%	$S/2$	Error in miles	0.08	0.08	0.15	0.15
RE4	0.25%	D_T	contributed by	0.25	0.05	0.05	0.01
X5	0.30%**	$20T/3$	each element	0.60	0.12	0.06	0.01
X6	0.05%	$S_T/2$		0.05	0.05	0.10	0.10
S1	5 milliradians (constant)			0.50	0.10	0.10	0.02
S2	0.1 mile (constant)			0.10	0.10	0.10	0.10
rms Summation of Errors (miles)				1.32	0.41	0.40	0.36
Maximum Error across C_T (miles)			Calculated	1.32	0.41	0.40	0.36
			Specified	2.00	0.50	0.50	0.50
Maximum Error in T (minutes)			Calculated	0.40	0.12	0.06	0.05
			Specified	0.60	0.12	0.10	0.10

*0.05% potentiometer with 0.15% allowance for error due to loading
**0.10% potentiometer with 0.20% allowance for error due to loading

that causes servo S1 to position the resolver shaft to the tanker course, C_T. The output of the other resolver secondary coil is a voltage proportional to the tanker distance to fly, S_T times T, which is the resultant of the two input components. The resolver and servo transform Cartesian to polar coordinates. The servo fills one of the output requirements, driving a dial displaying tanker course C_T.

To satisfy the second requirement that time to fly T be set up on a shaft for display, a servo divides the tanker distance to fly, S_T times T, by tanker speed S_T. This is done by exciting potentiometer X5 with a constant voltage. When this potentiometer is positioned by hand input S_T, the output is a voltage proportional to tanker speed. If this voltage excites potentiometer X6, driven by the "time to fly" servo S2, the output is proportional to tanker distance to fly, S_T times T. The output of potentiometer X6 is then matched against the output of resolver RE4, and the difference is an error signal that positions servo S2. The servo shaft assumes a position proportional to time to fly T.

The lower part of Figure 2 shows that the instrumentation here results in a closed-loop circuit.

Computing circuit loading considerations and accuracy requirements, as shown in the following error analysis, determines the need for booster (100 per cent feedback) amplifiers at the inputs to resolvers RE3 and RE4. These amplifiers have high input impedance, low output impedance, and a highly accurate and stable gain of unity.

APPROXIMATE ERROR ANALYSIS

A simple error analysis is necessary to establish the computing element accuracies needed to meet overall instrument performance. If the functional diagram places too severe requirements on computing element accuracy, the instrumentation approach should be modified.

The specified maximum error of a computing element results from combined individual contributing errors. These are functions of materials characteristics, manufacturing and standardization tolerances, and in the case of electromagnetic elements, variations in voltage level, temperature and supply fre-

quency. Consequently, the accuracy of any random element can vary between a specified maximum and some realizable minimum value. It can be either positive or negative.

When a number of such elements are combined in a computing circuit, the composite error is less than the sum of the individual maximum errors. Experience has demonstrated that a root-mean-square summation of the individual computing element errors is a good representative performance figure for the computer.

It is helpful to make a table to evaluate the various component errors. An optimum allocation of these errors can be reached by successively modifying the error magnitudes assigned to each component.

Table 1 shows the results of an approximate error analysis for the demonstration problem. Although it is generally necessary to investigate a much greater number of configurations, Table 1 has been limited to those four cases defined by the conditions at the head of columns (4) to (7). The nature of the problem frequently yields considerably different errors along and across the solution vector. In these cases, the errors in the components of the solution vector must be separately computed. In this case, there are only minor dissymmetries which are negligible for an approximate error analysis.

The lower part of Table 1 shows the rms summation of the contributing errors taken as equal along and across solution vector D_T. Errors along D_T are errors in time to fly T, and errors across D_T are errors in tanker course C_T. Note that the error contributions of the booster amplifiers (A1, A2, A3) are not tabulated at this stage. Their accuracy requirements can be decided during the final error analysis and specified so that they contribute negligible error to the overall solution.

FINAL INSTRUMENTATION

The functional designer, having established basic configuration of the analog instrumentation and order of accuracy of the various computing elements, now can proceed. Figure 3 is a two-line functional diagram that defines the computing circuitry in greater detail. It includes computing element interconnections, electrical and mechanical scaling, and servo design considerations.

Computing Elements

Standard electromagnetic resolvers generate trigonometric functions. Linear slidewire potentiometers multiply and convert mechanical shaft positions to scaled voltages. Resolvers and potentiometers are available in a wide range of physical and electrical characteristics. Limits of rotation, overall resistance, precision of overall rotation, linearity, resolution, power dissipation, and economy dictate the choice. Additions and subtractions are done by series connection of scaled voltages.

Loading Considerations

Except in the most elementary problems, computing elements must be cascaded. Connecting a resistance load to a resistive element introduces ratio errors. Reactive loads introduce phase shift, affecting servo design and performance. Circuit loading problems can be eliminated by booster amplifiers. But instrumentation should be kept simple for reliability and economy.

Loading correction is a study in electric circuits. Techniques to minimize ratio error and phase shift include selection of optimum impedance levels, dummy loads to improve error distribution, and scaling corrections. These are not in Figure 3.

Potentiometers X3 and X5 must have low resistances to minimize ratio errors caused by loads X4 and X6. On the other hand, X4 and X6 should be high-resistance units to minimize loading X3 and X5, and to get high resolution. Their influence on the T servo response demands high resolution.

An external resistance equal to the potentiometer resistance is connected in series with X3 and X5, since the minimum aircraft speeds required are one-half maximum. This also reduces the power dissipation and linearity requirements in these elements. Potentiometers X1 and X2 must have low resistance to minimize ratio errors and phase shift caused by the moderate impedance resolvers that load them. Resonating the resolver input impedance with shunt capacitance (not shown) also reduces ratio error and phase shift. Ten-turn potentiometers are needed to satisfy power dissipation and precision requirements (see Table 1). Multi-turn potentiometers with single-wire elements are available for applications requiring infinite resolution.

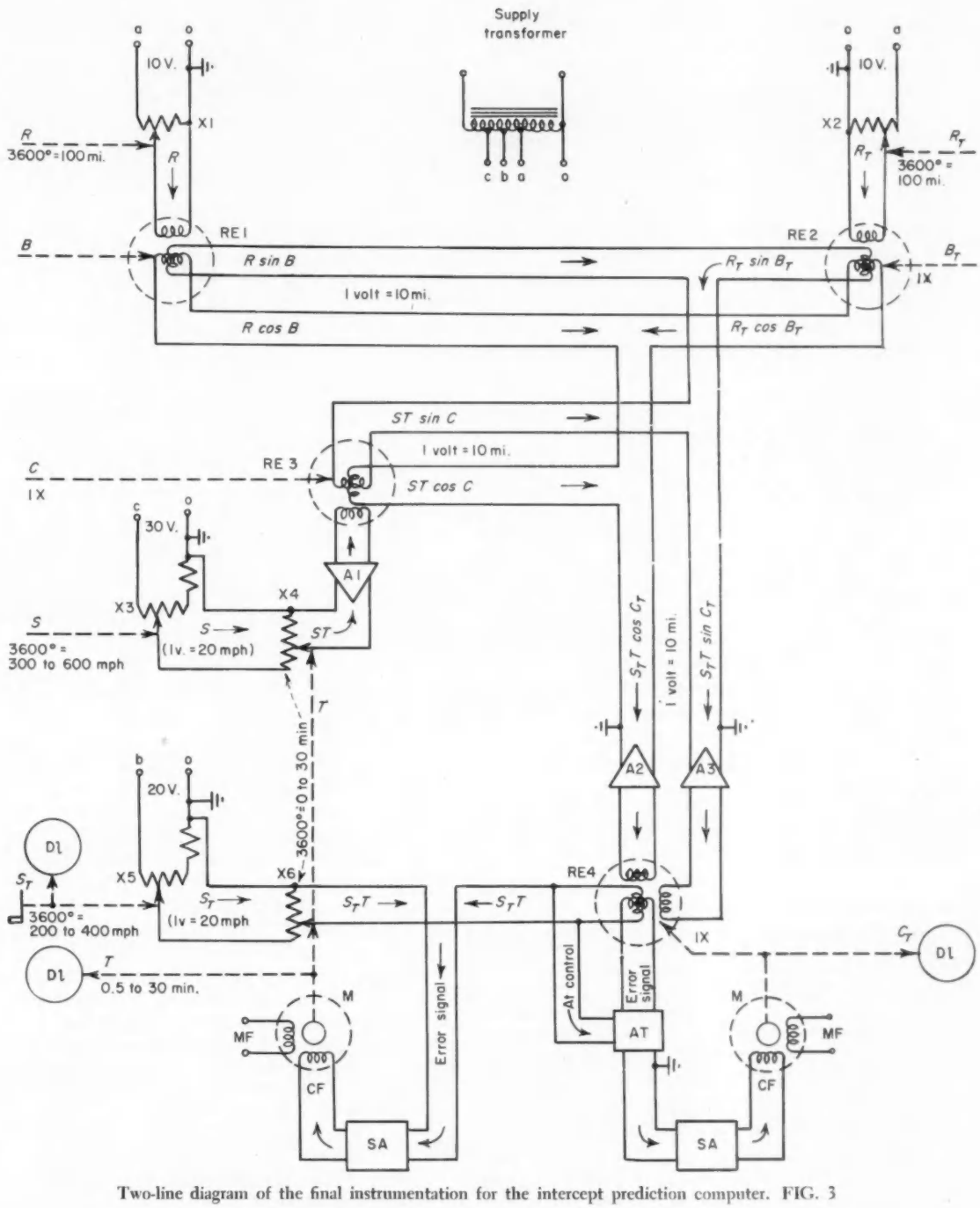
When desired accuracy cannot be achieved by direct-loading techniques, booster amplifiers must be used. Moderate gain amplifiers with about 100 per cent feedback can give unity gain with high stability. The application of booster amplifiers A1, A2, and A3 in Figure 3 is a typical example.

Circuits should be isolated where necessary to permit grounding of all amplifier inputs and to avoid recirculating grounds which introduce computing errors. Precision transformers can isolate computing circuits; and low accuracy transformers, servo error-signal circuits. The latter is preferable if a choice is possible.

Electrical Scaling

All resolvers are assumed in Figure 3 to have a primary to secondary voltage ratio of unity. Ratios in standard resolvers commonly vary from unity. This can be compensated for in the overall computing circuit with scaling corrections. A potentiometer has a unity output to input ratio when the zero to maximum range of the mechanical input equals the rotation between its electrical end points.

The electrical scaling of the computing circuits



Two-line diagram of the final instrumentation for the intercept prediction computer. FIG. 3

is shown in Figure 3. The basic scale of 1 volt equals 10 miles is used for distance functions, establishing the constant voltage inputs to potentiometers X1 and X2 at 10 volts (equivalent to 100 miles). The constant input to X3 is 30 volts, since a maximum target speed of 600 mph and a maximum time-to-fly of 30 minutes mean a maximum possible target travel of 300 miles at the output of X4. Note that, though the computer is not required to handle a target travel in excess of 150 miles, this circuit still must be scaled for the maximum values of the functions positioning the individual computing elements.

The constant input to potentiometer X5 is established at 20 volts. From this basic distance scale, the speed scale at the output of potentiometers X3 and X5 is 1 volt equals 20 miles per hour.

The three constant input voltages applied to the input of potentiometers X1, X2, X3, and X5 must be sufficiently accurate with respect to one another to introduce negligible solution error. If the 10-volt input to potentiometers X1 and X2 (connected in parallel) is taken as the reference, the 20- and 30-volt constant inputs can easily be established within 0.1 per cent by a tapped autotransformer, since circuit isolation is not required. It is only necessary to maintain the relative accuracy between these three constant input voltages, not absolute voltage levels.

Mechanical Scaling

Mechanical scaling establishes proper relative rotation between the various mechanically coupled computing elements driven by a given function. The scaling is done by gearing or other synchronous mechanical coupling. High accuracy is possible. Backlash introduces positional errors, however, and must be limited to be compatible with computing element accuracy.

Resolver shafts are positioned in this problem at one-speed (1X), i.e., one turn of the resolver for 360 degrees change of the positioning function.

The potentiometers are ten-turn units with 3,600 degrees between their electrical end points. Their shafts must rotate at the proper relative speed, so that the full range of the driving function covers 3,600 degrees.

Other mechanically driven devices in a computing unit must be properly designated by limits of rotation and relative shaft speeds.

Servo Performance Requirements

The performance demands of the overall computer dictate servo performance specifications. These decide the type and speed of the servo motor, the servo amplifier power and gain characteristics, the kind and amount of damping, and the compliance permissible in mechanical interconnections. These specifications also define the friction and inertia of the mechanical load, the static accuracy, the accuracy under velocity and acceleration conditions, and the dynamic response to step functions.

Servo Error Signal Sensitivity

The sensitivity of the error signal—the magnitude of the error signal developed for a forced unit-displacement of the servo—has a significant effect on servo design. All other conditions being equal, high sensitivity requires less voltage gain in the servo amplifier. When the sensitivity is variable, hindering proper servo performance over the range of variance, an attenuator is needed in the error signal circuit to minimize the variation.

In the case of servo T, if tanker speed S_T is set at the mid range (300 mph), a displacement of the shaft of 0.01 minute produces an error signal of 5 millivolts. For the corresponding maximum and minimum speed settings (400 and 200 mph) the error signal is 7 and 3.5 millivolts, respectively. This small variation in sensitivity is not significant.

For the C_T servo, however, the error signal sensitivity has a considerably greater variation. When tanker distance to fly D_T is at its maximum of 100 miles, the maximum voltage vector in resolver RE4 is 10 volts. At the minimum D_T of 2 miles, the voltage vector is only 0.2 volt. The error signal sensitivity would thus vary between 10 and 0.2 millivolts per milliradian, respectively. Since acceptable servo performance is not practical with a 50-to-1 variation in sensitivity, an attenuator, AT, is used in the error signal circuit. The attenuator is an amplifier with a gain inversely proportional to control signal D_T. If the attenuator has a maximum gain of 50 when D_T is 2 yards, then a constant sensitivity of 10 millivolts per milliradian is attained at its output. Low accuracy is generally adequate.

Effects of Quadrature and Harmonics

All computing voltages are called in-phase voltages to differentiate them from undesirable quadrature voltages caused by reactive computing elements. The error signals in an analog computer are derived by comparing two in-phase computing voltages either by direct voltage subtraction or magnetically within a resolver, such as in RE4. If these voltages are not well matched in phase, high quadrature voltage develops. If it saturates the motor amplifier, servo performance deteriorates.

Harmonics either in the computer voltage supply or generated by the various computing elements also can help saturate servo amplifiers. This is particularly important if electromagnetic computing elements are used. Harmonics undergo phase shifts different from the fundamental computing frequency when passing through reactive elements. They may not balance out, therefore, when two computing voltages are matched to get an error signal.

FINAL ERROR ANALYSIS

Now that the instrumentation is final, do a more detailed error analysis. This will finally decide the computing element and servo accuracy requirements.

Here the functional designer must work out the loading problems in greater detail. He must investigate ways to optimize error distributions found by the approximate analysis. Careful review at this time may reveal the need to tighten certain component accuracies. Or it may permit lower accuracy or circuit simplification.

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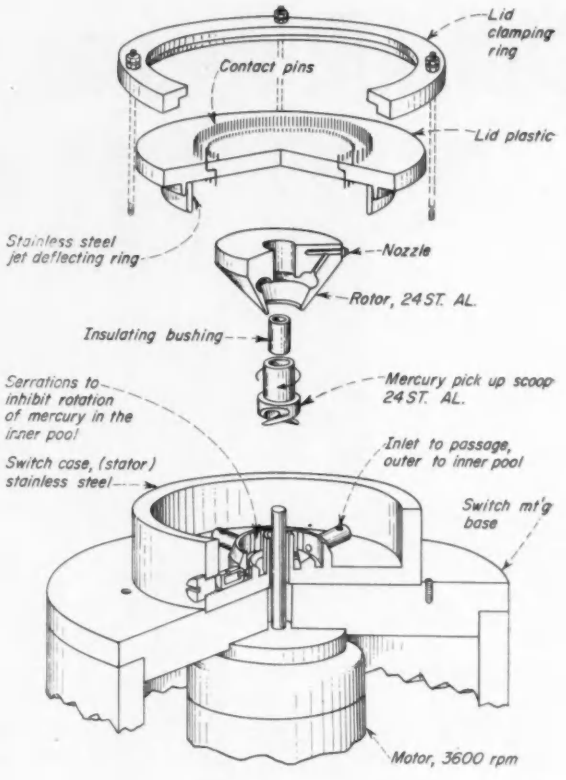
Quicksilver Quickens Telemetering Switch's Sampling Pace

This Mercury-go-round squirts the liquid metal through a hair-sized nozzle to switch signal samples at 12,000 per sec without contact wear or bounce.


Lid clamping ring
Contact pins
Lid plastic
Stainless steel jet deflecting ring
Nozzle
Rotor, 24ST. AL.
Insulating bushing
Mercury pick up scoop 24ST. AL.
Serrations to inhibit rotation of mercury in the inner pool
Inlet to passage, outer to inner pool
Switch case, (stator) stainless steel
Switch mt'g base
Motor, 3600 rpm

An exploded view of the rotary jet switch. Fig. 1

By W. R. DAVIS and J. H. DERRY,
Detroit Controls Corp.

The idea of using a stream of conducting liquid, like mercury, as the wiper in a rotary switch was first mentioned in a patent dated 1901. It lay dormant until recently, when a number of groups working on telemetering revived interest in mercury rotary switching.

THE PROBLEM

In one basic type of telemetering system, a transmitter obtains a sample of each of several signal sources. It transmits these samples over a channel to a distant receiver which separates them into independent channels for observation or recording.

A simple way to make a telemetering system that operates this way is to use two synchronized rotary switches. Each position or contact of the transmitting switch is connected to a different signal source. The rotor, or wiper, turns continuously, sending out a sample of each input with each complete turn. A similar switch is used as a receiver.

The receiver's wiper, synchronized with the transmitter's, distributes the incoming samples to each of its contacts in the same order as they were transmitted. Of course, the faster the original signals are changing, the faster they must be sampled; otherwise some inputs might go through great changes between samples. Commutators with as many as 100 contacts have been operated at up to 2,000 rpm to accomplish this. However, high speeds tend to create contact bounce and rapid wear of rubbing surfaces. Contact bounce, which varies "on" time for each contact or alters its resistance, affects the character of each sample. As a result, there has been interest in developing new types of rotary switches for high-speed telemetering.

One group so interested is the University of California Radiation Laboratory. After carefully considering a variety of possibilities, UCRL decided to experiment with a mercury jet switch for a telemetering system. The approach looked promising, and as a result, Detroit Control Corp. received a contract in 1954 to develop and build two synchronized mercury jet switches.

SWITCH OPERATION

The design of the mercury pump for the switch, built by Detroit Controls, is very simple: the spinning rotor scoops up mercury from a sump, or well, at the bottom of the switch, lifting it to a circular pool. Centrifugal force develops enough force to eject the mercury from this pool through a small nozzle at a speed of 63 ft per sec. Figure 1 is an exploded view of the inside of the switch, showing the mechanical simplicity of the pump.

The use of an acrylic plastic rotor initially caused trouble by allowing static electricity, created by atomization and swirling of the mercury, to accumulate to high potentials and then discharge to the central pool, creating a noisy spike (or pulse). Substituting a metal rotor to conduct the static charges to the central pool cleared up most of this difficulty. The magnitude of the static noise remaining after this change is relatively small. With the switch working into a ½ megohm load, 1 v noise-spikes lasting about 20 microsecs are created at a rate of about one per sec. Into a 10,000 ohm load spikes of ½ v magnitude lasting one microsec occur about once every two minutes. These noise levels, especially with 10,000 ohms impedance, are relatively inconsequential in terms of the accuracy of the entire system.

The lid of the machine, its stator, is shown in Figure 2 (looking down from the outside). It contains 240 stainless steel pins 0.014 in. diam on a 3 in. diam circle. This means they are 0.040 in. center to center or 1½ deg apart. The space between pins is therefore 0.026 in. With this spacing, it was found that a jet nozzle bore range from 0.003 to 0.007 in. diam provided best operation. Na-

turally, the wider the nozzle the wider the jet, and the wider the jet the longer the contact or dwell time on each pin. With the 0.026 edge to edge spacing of the pins, the switch operates as a "shorting" type. That is, it makes contact with the next point before breaking with the one being left. By using only alternate pins, a non-shorting 120 position switch is obtained. The intermediate contacts are referred to as "floating."

At rotor speeds of 60 rps, with a 120 position stator, 140 microsec elapse between identical portions of two successive contacts, so that 50 percent "on" time corresponds to 70 microsec. Using the 0.003 in. diam nozzle, with the floating pins removed from the stator, a minimum "on" time of 28 per cent is produced while with a 0.007 in. diam nozzle bore, this is 57 per cent "on" time.

By using these floating contacts, however, a maximum of 90 per cent "on" time can be achieved with 0.008 in. diam nozzle. The spacing between end of the nozzle and the contact pins was not critical within the range of 0.005 in. to 0.050 in.

High speed oscilloscope studies of a square wave produced by the switch indicate that the leading edge starts at the same place for each cycle, and requires less than one microsec for completion. Toward the trailing edge of the wave, however, the final 5 or 10 per cent of the pulse displays uncertain operation. This variation takes place only on the trailing edge, altering the length of the signal by a maximum of 10 per cent. Figure 3 is an example of this phenomenon.

The current handling capacity of the switch depends on the character of the load. Attempting to interrupt a current of 0.1 amp working into a 2000 ohm resistive load caused arcing at the contact pins, but interruption of 0.15 amp into a 10 ohm resistive load caused none. Currents up to 10 ma can be handled easily for most load conditions. The contact resistance of the switch is about 1.4 ohms in a 1 v circuit. There is the possibility of mercury skum (mercury oxide for the most part) clogging up the pump, but about one thousand operating hours have been logged to date and many more thousands should pass before danger of clogging. Rotor speeds of up to 100 rps have been obtained, providing up to 12,000 samples per sec.

PHASE SYNCHRONIZING SYSTEM

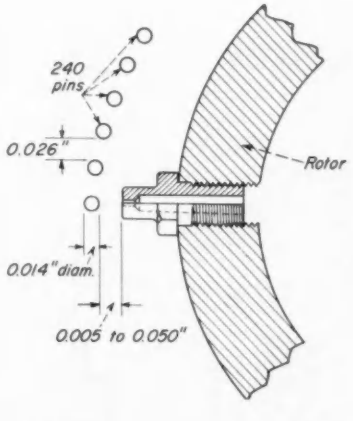
Because synchronous motors run exactly at line frequency, or some integral subfraction thereof, one of the simplest ways of keeping two remotely situated rotary switches synchronous is to drive each by a synchronous motor operating from a common power supply. It was discovered that many synchronous motors commercially available exhibit oscillations about true line phases. A sudden external torque or line voltage variation will cause this irregularity, which can alter the instantaneous phase match between two similar motors enough to reduce the effective contact dwell time by as much as 10 per cent. Both simple and compound flywheels were coupled to the motors in an attempt to smooth out and damp these oscillations, but the phase stability was still inadequate for the precise phase match desired. But an electrically damped hysteresis synchronous motor made by the Electric Indicator Co. of Springdale, Conn., was found to exhibit enough stability to limit maximum phase differences to hold the maximum dwell time reduction to about 3%.

The exact phase match of the two switches is achieved by a reference pin on each switch. The electrical phase of the power to one of the switches is advanced until the two pins are contacted simultaneously.

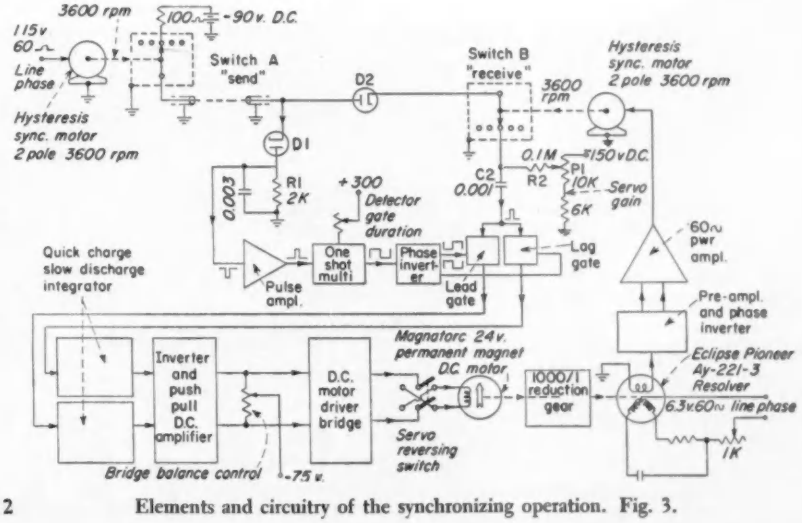
A block diagram of the system for automatically keeping the switches in phase is shown in Figure 4. The reference pins on each switch are maintained at a large negative bias, whereas the other circuits are at a zero or positive potential. Proper operation of the transmitter (send switch Figure 4) causes a negative reference pulse to be generated across R 1. This pulse triggers a 60 cycle square wave reference (gating) voltage. Operation of the receive switch at an arbitrary phase with respect to the transmitter causes a positive error pulse to be generated across R 2. With the electronic "gates" this error pulse occurs in that half cycle of the reference voltage either before or after the one initiated by the reference pulse.

The phase-detected error pulse is then integrated, amplified, and applied to a dc motor. This motor drives, through a 1,000 to 1 reduction gear, a resolver phase shifter capable of advancing the phase of the power to the receiver through 360 deg in a continuous fashion. By this means the phase of the receiver rotor is advanced until the receiver reference pin is contacted at the same time as the reference pin in the transmitter.

This causes the error pulse to disappear, (because of the high source impedance of the negative bias voltage on the receiver compared to the low source impedance of the bias on the transmitter) and thus the motor-resolver stops.



Relationship of pins to nozzle. Fig. 2



Elements and circuitry of the synchronizing operation. Fig. 3.

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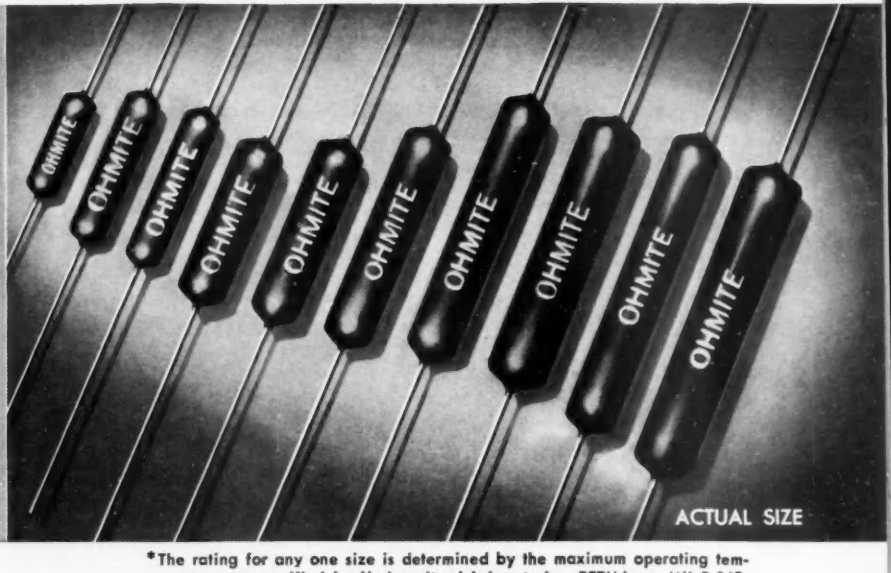

*The rating for any one size is determined by the maximum operating temperature as specified by Underwriters' Laboratories, RETMA, or MIL-R-26B.

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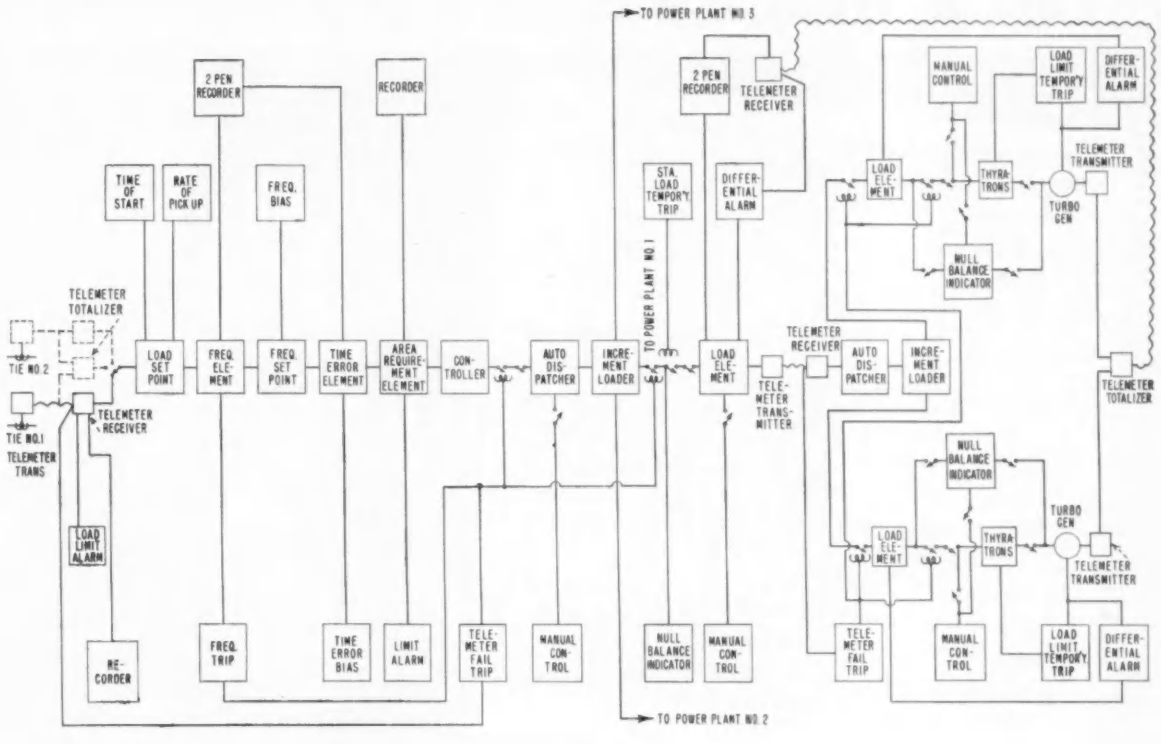

Simple Loop Controls Power for Whole State

Power networks can be regulated with new levels of precision by a compact automatic control system built on a simple proportional-plus-reset loop.

S. CUMMINGS
Minneapolis-Honeywell Regulator Co.

In a recent test of the fundamental parts of the Minneapolis-Honeywell load-frequency control system at Denison Dam, Tex., the load dispatcher was able to control a power system serving the entire state. By regulating the output of only two 37.5 kva hydro generators, he was able to hold the frequency of a 1,000 megawatt system within plus or minus 0.03 cycles, in spite of rapid load swings caused by the fluctuating demands of large steel mills in the southern part of the state. The first complete installation of the basic system described by the diagram is taking place at the Niagara Mohawk Power Corp. to control the Huntley and Dunkirk stations from a dispatcher's office in Buffalo.

Formidable as the diagram may seem, its objective is basic enough: the economical regulation of transmission line load and frequency through the control of the generators in the system. Electric companies sell current to each other at different times during the day, depending on local supply and demand. This process is called interchange. Another variable that is of concern to power companies, besides load and frequency, is the total accumulation of time error that results from frequency drift and is registered by all the clocks in the system. When a number of generators at different locations having different capacity and efficiency characteristics are joined in a system, the contributions that each shall make to the requirements of the entire network become no easy thing to calculate.

In a conventional control system, the load dispatcher notes the interchange, frequency and time errors. He determines the load centers and telephones instructions to each station in the power system so that all stations will divide the new total load in the most economical manner. To do this, the station operators vary the speed adjustment setting of the governors so that all generators will carry loads according to their incremental heat rate curves. A penalty factor has been added to provide for transmission losses.

The complexity of the system and the mass of the economics involved would seem to warrant the use of equipment for better regulation than is possible with human operators.

The present system can best be

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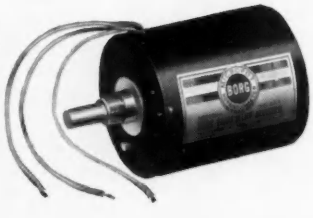

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BORG EQUIPMENT DIVISION
THE GEORGE W. BORG CORPORATION
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described as being of a computer-command type with a computer at the pinnacle of a pyramid. This pinnacle represents the dispatcher's office. Commands issue from this point to all stations and the various machines in these stations that are on control. These stations represent the broad base of the pyramid. The computer, which is called Area Requirement, adds the deviation error signals of the following quantities: 1) the tie-line deviation from set-point; 2) frequency deviation from set-point; 3) time error from zero time error.

THE DIAGRAM

Telemetered signals, showing load conditions (power consumption) in various areas are received in the chief dispatcher's office and added in a totalizer to give "net interchange" (total power exchange through the system). This quantity is compared with the schedule (the net interchange set point). The system also incorporates a program device which automatically adjusts the net interchange set point to allow for such known changes as industrial load in the morning, lunch hour lull, and extra loads during special seasons. A time delay mechanism allows the program to be set some hours before these changes actually become operative. If a difference between schedule and net interchange is detected an error signal is forwarded.

Similarly, system frequency is compared with its setpoint and system time is compared with standard time. Any error signals are added together and applied as input to the area-requirement computer. The net error signal goes from the area-requirement computer to a controller that incorporates proportional and reset actions. These may operate together or separately. The resultant proportional-plus-reset corrective signal is sent to an incremental loader on which curves have been laid out for the various stations according to the optimum power contributions each should make under different load conditions of the network. These curves of each station's contribution are based on their heat rates (efficiency) and may include a penalty factor set in manually or automatically to account for transmission losses.

That is, even though station A might develop 100 kw much more efficiently than station B, the distance between A and the load might, after the transmission loss had been noted, make it more economical for station B to supply the need.

The separate signals from the incremental loader are telemetered to the various stations being controlled. Within each station, a signal is sent to a station incremental loader, which is similar to the system incremental loader. Just as the incremental loader was set to regulate the power output of each station for maximum efficiency in the net, now in the station the incremental loader will distribute the work to each generator according to its heat rate. As the generators react to the new signals from their incremental loader, the operation of the entire system is completed.

The sum total of information obtained at the tie points and from other sources has been delivered to a controller, relayed to the generators as a control signal, and fed back as power generated to the tie points. The system sounds alarms in the event of component failure and has high-low limits.

PROPORTIONAL AND RESET ACTION

The rapid response of the control system to sharp load swings is made possible by the addition of a proportional signal to the reset control signal. When a sudden sharp load change, or transient, occurs, the proportional signal, a fast speed signal, is directly proportional to the rate of the transient's appearance, and the rate of the transient's disappearance is directly reflected by the ratio of the disappearance of the proportional signal. The reset signal is a slow speed signal, operating simultaneously but at such a slow rate that its effect is negligible in the case of a sudden transient. If the transient is of longer duration (a square wave instead of a pip) the "proportional-plus-reset" action consists of the following. The proportional signal disappears as the system returns to balance, but the reset part of the signal continues to feed into the incremental loader to return the actual frequency to its control point.

The individual circuits of the load-frequency control system are elementary, and compounding them is relatively simple. Hence, we find that the basic notions of the instrument engineer make possible the assembly of a system for the automatic control of an entire electric power network for optimum economy and quality.

WHY USE IT?

It will be some time before we learn how long it takes for such a system to amortize itself. We know it reduces expenses because it gives closer control and faster correction than any other control method.

It will rarely reduce a payroll, because most power systems are down to minimum personnel already. A human being will always have to be in attendance for certain decisions on schedules, interchanges, routings, emergencies.

The electric utilities sell power, not voltage or frequency. But for many technical and economic reasons, voltage and frequency must be held constant. Of course, any excessive voltage would bring complaints of burned-out equipment. Many transformers, motors, heating elements, and other equipment don't operate properly or are damaged by low voltage.

Also remember that

$$P = E\,I = I^2R$$

and that transmission lines and all conductors heat up and deteriorate when carrying too heavy a current. So, when XYZ company starts up its rolling mill, it needs a certain amount of power (P) to turn the motor. If the voltage (E) is below standard, the motor will draw excessive current (I) in order to make the product E I equal the required P. The heavy current causes trouble all over; in the motor, on the transmission lines, transformer, generators, and so on. And because the resistance in alternating current lines is made up of reactances and inductances as well as straight resistances, the heavy current also fouls up phase relationships and power factors, causing the electric company to send out more power than it can charge for.

In the final analysis, it's in the best economic and public relations interests of an electric utility to maintain exact frequency and to balance demand and output.

FEEDBACK FACT

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Solved: By Armour Research's "aerosoloscope" which optically metes, sizes, then counts the stuff."

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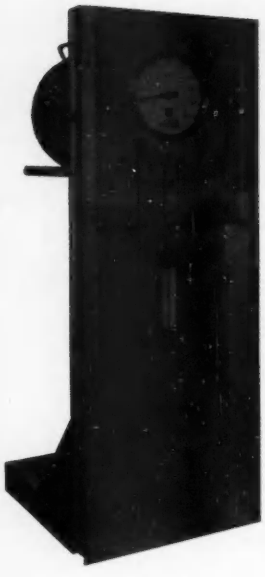

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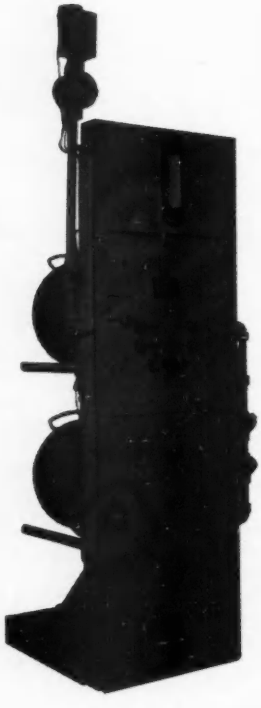

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Servos vs. Spirals Make Light Planes Safer

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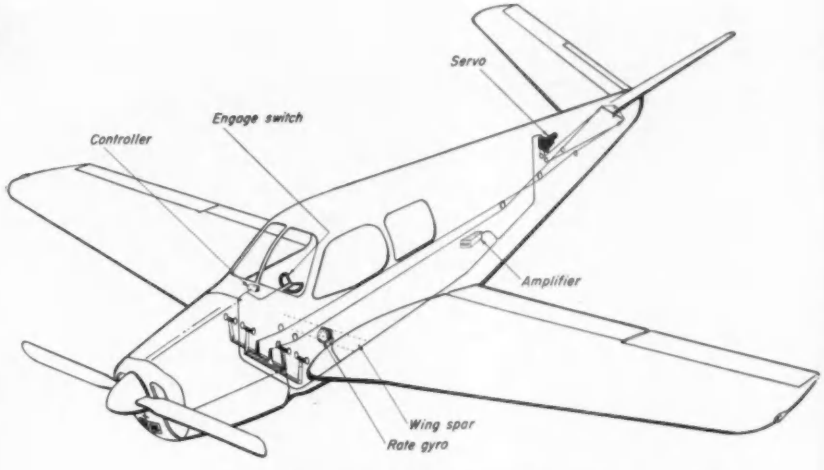
Here's a reliable yet inexpensive system that prevents the often-fatal spiral dive than threatens light planes flown by inexperienced hands.



A typical ARCON installation. Gyro responds only to rate of turn about a vertical axis relative to plane. FIG. 1

Light planes with too few instruments, and pilots with insufficient experience make a dangerous combination. A sudden meeting with IFR (instrument flight rules) weather, no contact with the ground and the horizon, and the result often is a "graveyard spiral." The name fits because few pilots ever recover from this "maneuver."

With no real or artificial horizon, a plane quickly departs from level flight. In a slight bank, it will turn and lose altitude. The pilot may notice that he is losing altitude and gaining airspeed. If he pulls back on his stick he tightens his spiral and he still gains airspeed. The outcome is usually either structural failure of the plane due to high acceleration forces, or a crash.

The "ARCON" system (automatic rudder control) prevents the initial turn that could end in the graveyard spiral. The entire system is shown in Figure 1.

ARCON gets its sense from a rate gyro that is extremely sensitive (1 volt output for 36 deg per min) to turning of the plane. ARCON drives the plane's rudder to get an opposing rate of turn. Since the system is a rate servo, it needs an error to act. Though this error is kept small through very high loop gain, a long-time (order of many minutes) drift in the aircraft's heading may result. And ARCON is a single-axis system only. It is not, therefore, an autopilot.

The system is diagrammed in Figure 2. The rate gyro produces an ac output voltage with an amplitude proportional to turning rate, and phase dependent on direction of turn. The bridge rectifiers change the signal to dc for the control windings of the magnetic amplifiers (there are no vacuum tubes anywhere). The magnetic amplifiers give ac outputs again, but at a much higher power level. This signal is then rectified to energize magnetic particle clutches.

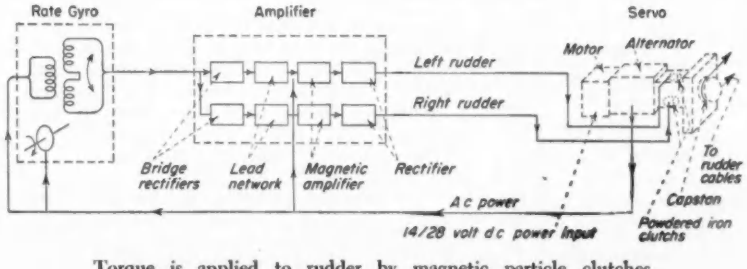
The clutches are geared to a continuously-running dc motor. They supply torque to the rudder proportional to the rate of turn signal from the gyro. Servo response is excellent because of the lead circuits in the amplifier and the low time constant of the clutches. Full output torque is reached in 10 millisec.

Rudder direction depends on the clutch energized. The rudder is connected to the clutches through the cables and capstan. The capstan assembly is mounted on the airframe, so the servo drive can be removed without disturbing the cable rigging..

The drive motor runs on the plane's 12- or 24-volt dc electrical system, and is rated at 1/40 hp at 5,000 rpm. A unique feature is the ac alternator, on the same shaft as the drive motor. It supplies 115 volts three-phase at 400 cps for the gyro and magnetic amplifiers and is rated at 15 volt-amperes.

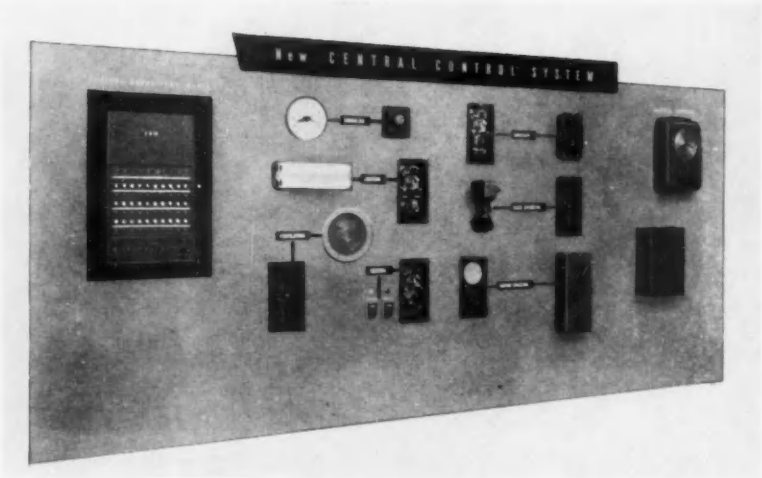
The entire system is used in both good weather and IFR weather. A slip clutch in the capstan assembly permits the pilot to operate the rudder normally, overriding ARCON in case of malfunction or to make small changes in course.

The system has been engineered for maximum reliability. The magnetic amplifiers and the gyro are hermetically sealed. All wiring is etched to eliminate breakage from vibration. The entire ARCON system weighs only fifteen pounds. It costs $800, plus installation.



Torque is applied to rudder by magnetic particle clutches. Servo loop is closed by reaction of air on rudder surface. FIG. 2

NEW PRODUCTS



LISTING IN GROUPS

1- 4 Supervisory Systems
5- 8 Pumps in Control
9-14 Torque and Its Transmission
15-23 Digital Devices
24-28 Valves for Control
29-44 Powering Products
45-48 Relays & Switches

A CENTRAL PROGRAMMER PULSE-COMMANDS UP TO 40 OPERATIONS USING CODED RELAYS . . .

The panel above is strictly for demonstration. IBM has found it a handy way to display the components and functions in its new Central Control System—an automatic programming scheme which will start and stop up to 40 groups of remote operations in a process, plant, or large land area.

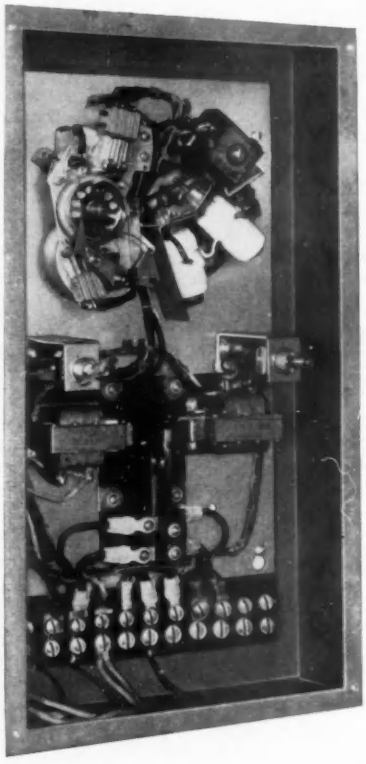
On the left in the board above is the master programming panel. This is simply an electronic rotary transmitter which generates "command" pulses of from 2,106 to 19,000 cycles. These are coupled directly into a plant's low voltage lighting circuit or to high-voltage power distribution systems. On the panel's face are inactivating switches and bull's-eyes lights identifying each on-off circuit.

A look at the other components on the demonstration board shows what the system can do to a plant or process. The pulse commands, for example, start motors, turn on plant lights, operate valves, switch equipment, and even toot the lunch whistle.

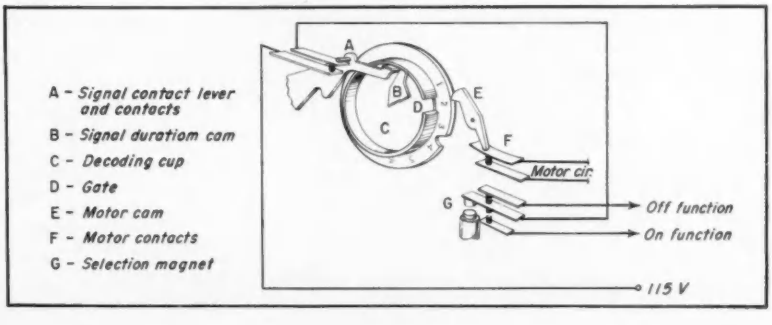
Note that every operating function on the display board is flanked by a black box. This is the function actuating unit, an IBM special called a Dual Coded Relay. Four types are available. All consist of a basic electronic receiver, an electro-mechanical decoding device, and load relays. The receiver selects the tuned frequency signal, amplifies it, and applies it to a cold cathode tube. This triggers the decoding mechanism, which can pinpoint any one of ten "on" or "off" codes which come in on the one carrier frequency and operate the appropriate relay.

As the accompanying pictures show, the decoder is quite simple. It consists of a motor-driven cup with a gate designed to accept signals which are properly coded. The incoming pulses and their time duration drive this cup around to each of ten positions. Signal contacts are made through positions of a contact lever and signal duration cam. *International Business Machines Corp., 590 Madison Avenue, New York 22, N. Y.*

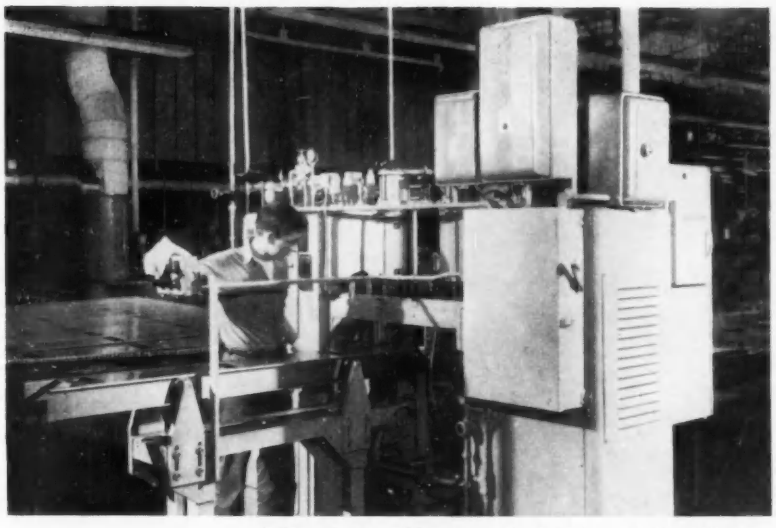
Circle No. 1 on reply card



The Dual Coded Relay with its cover removed. Note manual toggle and key for pulse lock-out. Sketched below is the rotating coded receiver cup and its working parts.



. . . AND THIS CENTRAL SUPERVISOR EMPLOYS STATIC SWITCHING FOR PRODUCTION-PROCESS CONTROL



A bus duct welder is controlled by a "Cypak" system—the standard panel studied by girl—replacing the relay control cabinet below it.

Westinghouse has drawn upon its know-how in magnetism and semiconductors in designing this new central control system for sequencing and scheduling production-processing operations. At the heart of the design, called the "Cypak," are static devices —the magamp and the diode—that perform functions normally handled by electro-mechanical relays.

The pictures above show space saved by a typical "Cypak" system. This is an automatic bus duct welder, with controls housed in cabinets to the right of the machine. Function of the controls: to repetitively position and weld a piece of work, with necessary starting, stopping, and interlocking features. The young lady has unveiled the compact "Cypak" panel with its static control devices. Shown below the "Cypak" is the original relay system that it replaced in this welding operation.

Some other "Cypak" systems now under test: a simple punch-press control and a more complicated spiral milling machine control, an ingot feed and removal system for a soaking pit, a programmed blast furnace charger, an electrical power system supervisor, and an automatically controlled six-story elevator.

What's the big advantage of the Westinghouse static switching circuits? Company designers boil it down to the systems approach. Their study of industrial relay systems convinced them that relays were mainly used for problems of information processing rather than power switching. Relays were actuated at definite speeds, distances, positions. Hence their job was mainly digital rather than analog in function.

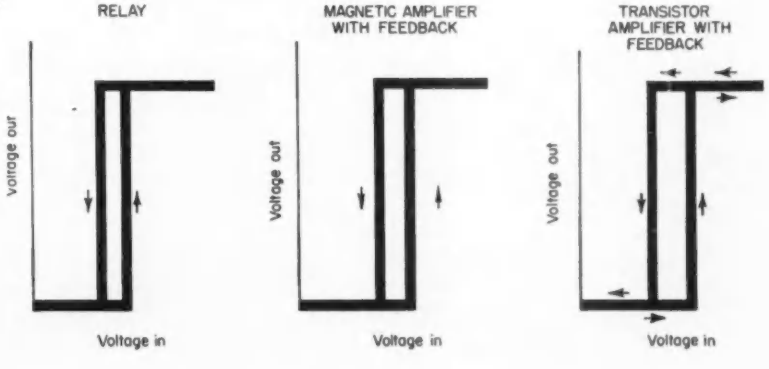
So the big advantage comes through substitution of digitally-oriented solid-state devices for relays. The former have no moving parts, are more compact, and are faster.

Westinghouse has apparently carried its basic new approach to industrial switching to a solid commercial level. While similar in function to computer elements, the "Cypak" building blocks are larger, heavier, and power-rated to fit tough industrial chores. At present, the basic magamp unit is about five in. square and one-half in. thick, with one or two doughnut-like magnetic cores mounted on the flat base. The transistor unit looks like a small metal box with prongs. Circuitry in each unit and their hook-up in the control panel depends on the control job being handled. *Westinghouse Electric Corp., Pittsburgh, Pa.*

Circle No. 2 on reply card

IMPROVING ON THE RELAY?

Comparison of the characteristic curves for the relay, magnetic circuit, and transistor circuit reveals interesting similarities. All are sharp, step-function curves providing memory and comparative freedom from associated components. And all provide an output larger than input, which permits cascade connection. Because of these similarities, Westinghouse engineers feel that the more durable, rapid solid-state devices can be substituted for many industrial switching jobs.



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Nine different styles . . . with or without union outlet, as well as offset and jacketed valves.

Features available include safety shut-off; double-seating stem for repacking under pressure; regular or quick-closing stem and lever; regrindable and renewable seats; pressure bleeder valve and test gage connection; outside screw and yoke when desired; throttling stem when desired.

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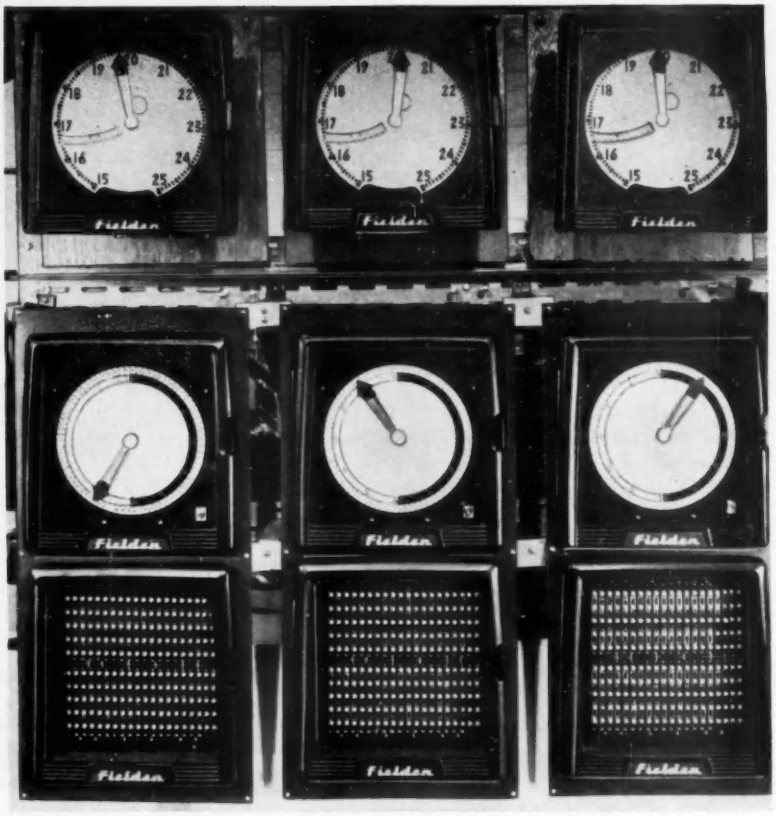
NEW PRODUCTS



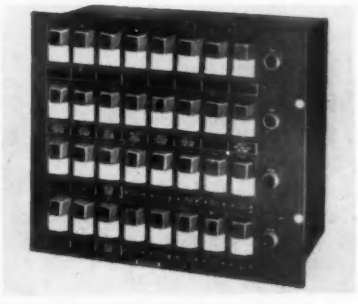
VERSATILE SCANNER oversees many variables, checks one each second, persists in signalling error.

The three tri-component scanners pictured are undergoing final tests during manufacture. Each scanner can oversee 6, 12, 24, 48, or more different industrial processes from one point. The system can monitor such variables as level, temperature, thickness, mechanical movement, tolerances, weight, and pressure.

As shown, the 76-point unit at the top indicates temperature at each step in a process. The unit in the middle indicates the step being controlled. If the temperature of a step deviates from a prescribed setting, the instrument stops automatically, showing location and extent of the trouble. Pressing the reset button restarts the scanner. However, unless the condition is corrected, or a by-pass connection made with the sliding connectors shown in the bottom case, the scanner again will stop at the over-temperature point.

The speed of scanning is largely determined by the number of points to be scanned. The maximum rate is one point per sec. Associated control systems can be actuated by the scanner to correct any process that deviates beyond the pre-set control zone. *Fielden Instrument Division, Robertshaw-Fulton Controls Co., 2920 N. 4th St., Phila., Pa.*

Circle No. 3 on reply card



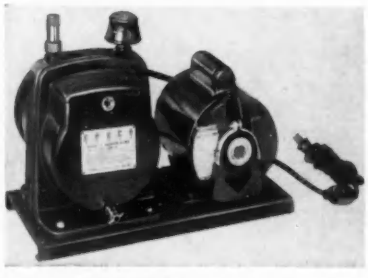
NIMBLE ANNUNCIATOR alerts, indicates, monitors.

This new annunciator system does three jobs in the control of off-normal conditions in a process: provides a visual and audible alarm, shows the first failure of a sequential operation,

and, through an interlocking circuit, automatically selects and monitors shut-down equipment. Components are standard and unitized, with "pluggable" hermetically sealed relay units. *Industrial Automation Co., 2415 West Montrose Ave., Chicago, Ill.*

Circle No. 4 on reply card

PUMPS IN CONTROL



HIGH VACUUM pumps operate silently.

Manufacturer says the way this Hyvac 7 vacuum pump operates should be music to the rattle-weary ears of technicians, but if all is true, there should be no music at all. Quiet and vibration free, the small (8½ x 17½ x 13), 89 lb unit is said to have more capacity per cubic ft than any other high vacuum pump on the market. It displaces 70 liters of air per min, pumping from atmospheric to ultimate pressure in less than 5 min. Pump is equipped with ⅓ hp motor for 115-230 v or 220/440v (three phase). An explosion-proof motor also is available. *Central Scientific Co., 1700 Irving Park Rd., Chicago, Ill.*

Circle No. 5 on reply card

SELF-PRIMING CENTRIFUGAL has high secondary pressure.

Here is a centrifugal pump with what is said to be a revolutionary abil-

shocking...?

FOR ELECTRO-MECHANICAL INSTALLATIONS THAT MUST WITHSTAND SEVERE SHOCK . . . CALL P M I

Electro-Mechanical assemblies, simple or complex, that's our business. Slip ring (collector ring) assemblies are our specialty. Devices we have produced vary from one-circuit miniature slip ring assemblies to 500 circuit complete installations. Give us a call for free estimates.

PROJECT 135C102
Produced for U. S. Navy Bu. Ord. SRA to withstand 100G shock load to Gov't specification Mil-T-17113. 260 circuits.

PMI

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STAMFORD, CONNECTICUT

BARBER COLMAN

d-c motors

chosen to drive new Vought Photographic Recorders

Designed primarily for use on aircraft, the Vought 16 mm. Photographic Recorder takes up to 16 photos per second . . . and 4,000 individual pictures without reloading.

With its compact size . . . only 4" x 4¾" x 7⅝" . . . design of this recorder called for a highly efficient, geared-head driven motor that would occupy little space. For this a Barber-Colman type BYLM permanent-magnet motor was selected.

If you have a design problem that demands small size, d-c fractional hp motors of unusually high quality, high dependability, investigate the Barber-Colman line. Both permanent-magnet and split-series types . . . in various mountings and speeds with outputs up to 1/10 hp. Ideally suited to power electro-mechanical actuators, switches, blowers, programing devices, and various other applications . . .

THE VERSATILE LINE OF HIGH-QUALITY SMALL MOTORS

- Permanent-Magnet Motors
- Split-Series Motors
- Motors with Gearheads
- Motors with Filters
- Motors with Blowers

Write for free catalog No. 100

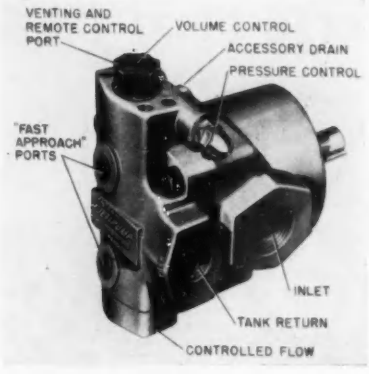
Barber-Colman Company

Dept. R, 1448 Rock Street, Rockford, Illinois

NEW PRODUCTS

ity to rapidly discharge air and vapor against a static head. The Multi-Prime, as it is called, comes in eight models, three for trucks without gear increasers, three with gear increasers with either right or left rotation, and two models for bulk plant use. Capacities range from 120 to 200 gpm. Granberg Corp., 1308-67*th* Street, Oakland 8, Calif.

Circle No. 6 on reply card

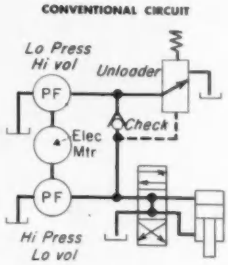


MULTIPUMP simplifies piping and maintenance headaches.

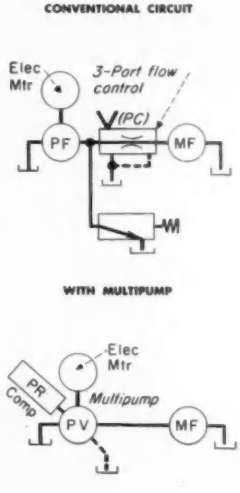
Wrapped up in this variable volume, vane-type pump are flow controls, relief valves, and the second pump used in dual pump circuits. The Denison Multipump takes care of them all. As shown in the comparative block diagram it has operating features not usual for one unit. It is available in capacities of 5, 15, and 25 gpm at 1,200 rpm, all at 1,000 psi continuous duty.

While the Multipump's delivery can be varied—fingertip pressure on the control knob is all that's needed—output remains within 5 per cent of constancy. When system pressure reaches a preset maximum, delivery is reduced to the point required to maintain the pressure constant, excess flow unloading to the tank. Other important features are a remote control port, a venting port, substitution of stem control for the volume control knob, a fast approach port, and an accessory drain. Constant volume with variable shaft speed also is provided.

The block diagrams show how the Multipump replaces conventional circuits. The first illustrates dual pump use, with one pump for high volume at low pressure and another for low volume at high pressure. The second



circuit shows the Multipump's constant volume with variable speed drive. Only the necessary oil is



pumped, eliminating relief, unloading, check, or by-pass valves. *Denison Engineering Co., 1170 Dublin Road, Columbus 16 Ohio.*

Circle No. 7 on reply card

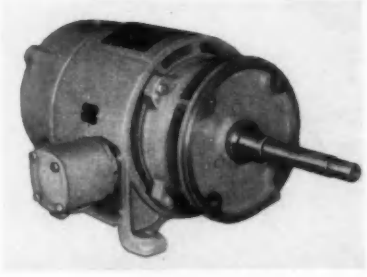
PROPORTIONING PUMP powered by air.

A double acting cylinder supplants a motor drive for metering and proportioning small volume flow in this pneumatically operated pump. Volume of liquid feed may be controlled

by length of stroke, air supply or valve actuation. The pump can be constructed of a variety of materials and its applications are numerous. *Hills McCanna Co., 3025 N. Western Ave, Chicago 18, Ill.*

Circle No. 8 on reply card

TORQUE AND ITS TRANSMISSION



PUMP MOTOR snuggles up to its job.

Here's a totally enclosed, explosion proof motor that virtually sits in the lap of a centrifugal pump. Its close coupling and double enclosure in larger ratings assure safe operations in damp, dusty, explosive, or corrosive atmospheres. A registered face-type mount bracket makes for true shaft alignment and simplifies pump mounting. Other features are solid flange and brass slinger, and precision ground shaft. Ratings range from 1½ to 25 hp. Larger ratings have aluminum cooling fans. All are fitted with sealed conduit boxes and have standardized castings, permanent lubrication and solid cast rotors. *U. S. Electrical Motors, Inc., Box 2058 Terminal Annex, Los Angeles 54, Calif.*

Circle No. 9 on reply card

TORQUE MULTIPLIER fits modest sized motors.

A Flumatic liquid torque multiplier is the first for gas and electric motors under 10 hp, says the manufacturer. The 3-piece, self contained unit provides gentle starts and stops and easy power take-offs. *Little Beaver Industries, Willoughby, Ohio*

Circle No. 10 on reply card

BARBER COLMAN

Small Motors

power the operating mechanism of new Stoner coffee vendor

A hot cup of coffee in eight seconds! That's what happens when you put a coin in the new Stoner "500" coffee vendor. This 500-cup capacity vending machine stores ingredients in stainless steel canisters, automatically mixes them "on order," then turns on an "empty" light and refuses the coin if the cup supply becomes exhausted. Operating mechanism of the Stoner vendor is powered by a Barber-Colman type FYAZ unidirectional geared motor. "Plus" features of this highly dependable motor include rugged, precision-built gear train . . . porous bronze bearings . . . hardened and ground stainless steel shafts . . . high starting torque. This application is just another example of how Barber-Colman Company supplies the exact motor needed to do the job. If you have a design problem involving small motors—open or enclosed—let Barber-Colman engineers help you solve it.

FREE DATA SERVICE ON WIDE LINE OF SMALL MOTORS.
The Barcol line includes unidirectional, synchronous, and reversible motors — up to 1/20 hp. With and without reduction gearing — open or enclosed types. Expert engineering service available. Write today, tell us your problem, ask for free data sheets

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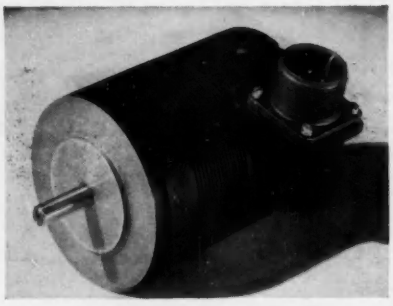

American Electric Model 323
ELEVON ACTUATOR
COMPLETELY QUALIFIED TO MIL M 7969 SPECS.

½ h.p. at 11,700 r.p.m. Teflon insulated for ambient temperatures from −65° F. to +160° F. Resists shock, vibration, salt spray, fungus and humidity. Operates on 200 V. line-to-line, 3 phase, 4 wire, 400 cycles. Furnished with or without AN Connector. Maximum length 3.75" Maximum O.D. 3".

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American Electric Miniatures are available for operation on 60, 400, 1600, or 2000 c.p.s. or on variable frequencies from 320 to 1200 c.p.s.

TWO TYPES:

INDUCTION—Output torque range from ½ in. oz. to 120 in. oz.

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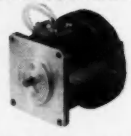
Ask for quotations on special requirements!

MODEL 182DA AXIAL FAN MOTOR—Totally enclosed, panel mount, screened intake, high temp. operation 20 CFM N.A.F.M. at free air. O.D. 1.45", 115 V., single phase, 400 cycle, or variable frequency models.



MODEL 430 AIRCRAFT DRIVE MOTOR—1/12 h.p. 11,000 r.p.m. Teflon insulation. −65° F. to +160° F. Completely qualified to MIL 7969 specs.

MODEL 313 COMBINATION DRIVE & BLOWER—½ h.p. at 7200 r.p.m. 400 cycle, 3 phase, 200 V. Continuous duty. Meets all general MIL specs.

MODEL 201D HYSTERESIS SYNCHRONOUS MOTOR—For Reference Timing Applications 12,000 r.p.m., 5 to 25 gm. cm. torque. Plain or geared shaft extensions.

FIELD ENGINEERING OFFICES in all major industrial areas in the United States and Canada.

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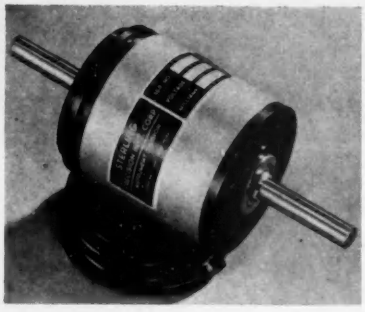


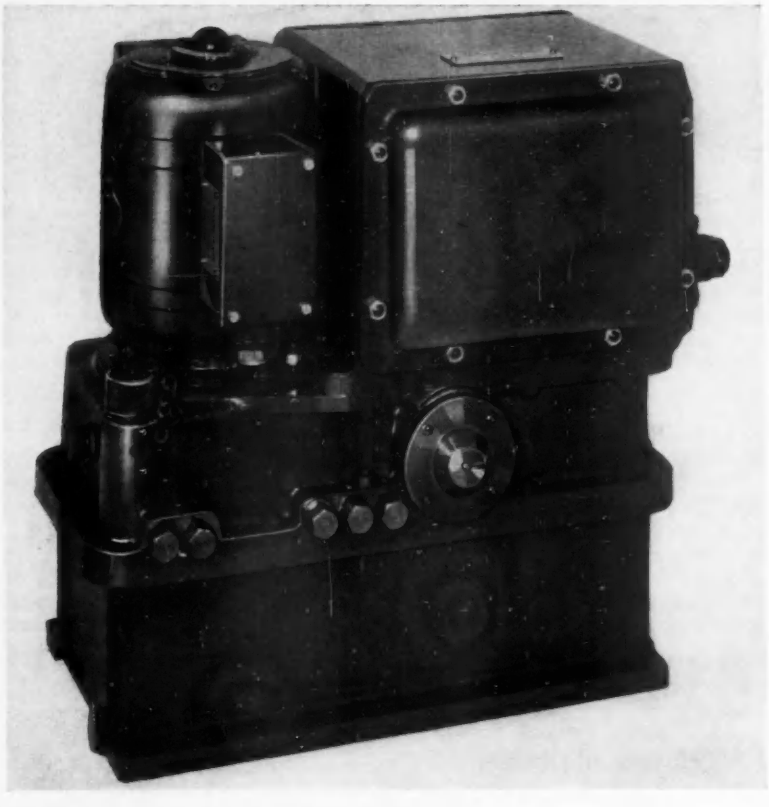
NEW CLUTCH serves servo systems.

Model T500 magnetic clutch, tested to meet army and navy specs, has servo mounting. Life tests, still in progress, indicate no change of performance although the clutch, carrying a 4 oz-in. load, has passed the million cycle mark. This is a positive-engagement friction type. *Sterling Precision Instrument Corp., Instrument Div., 34-17 Lawrence St., Flushing 54, N. Y.*

Characteristics

Case Size . . . 1.75 in. diam, 2.062 long
Engagement Time . 3 millisec, no load
Maximum No-slip Torque . . . 50 oz-in.
Backlash . . . . . 0.5 min.
Power . . . . . 3 watts at 24 vdc

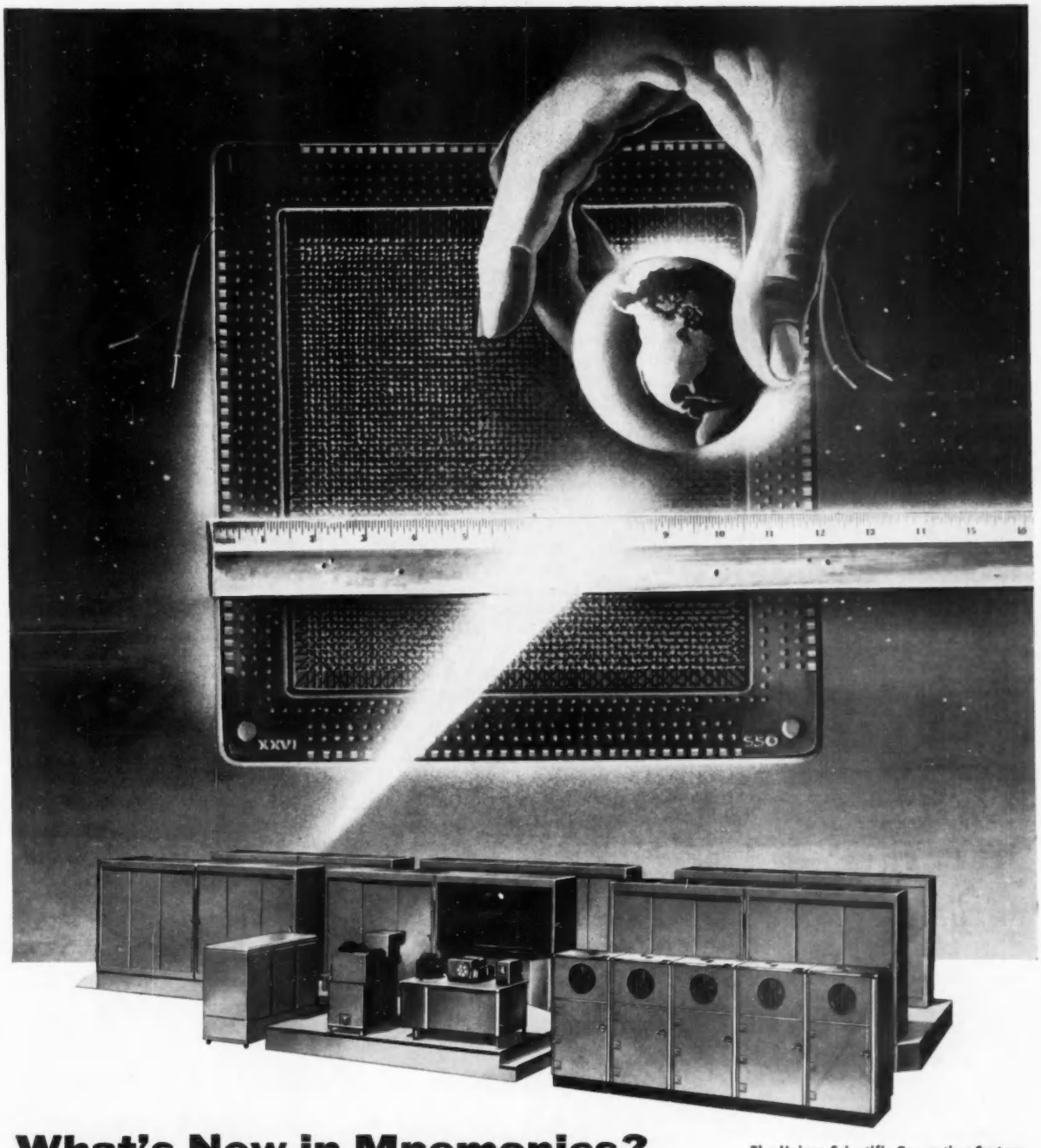
Circle No. 11 on reply card



HYDRAULIC RELAY packs precise power.

The D-696 Hydraulic Relay comes from England, where it was shown at the 1955 Physical Society Exhibition. A servo designed to control the Denny-Brown Ship Stabilizer, the relay fits many applications where large movement and torque is required from a proportionately small angular movement of a control element. Maximum torque is 40-ft.-lb. *Muirhead & Co. Limited, Beckenham, Kent, England; 677 Fifth Ave., N. Y.*

Circle No. 12 on reply card



What's New in Mnemonics?

The Univac Scientific Computing System

The news is that the magnetic-core memory has emerged from the computer laboratory and has been in customer use for approximately a year, passing all tests with flying colors. This new development has been pioneered by Remington Rand with the Univac Scientific—the first installation of a commercially available computer that successfully uses magnetic-core storage.

Mnemonics, says Webster, is "the art of improving the efficiency of the memory." And, as far as electronic computers are concerned, Remington Rand has clearly established its leadership in this art.

Illustrated above is a single plane of core storage, each of which holds 4,096 binary bits of information. Planes are wafer thin, and a stack capable of "remembering" 147,456 bits would measure only 13 inches in depth. The speed, economy, and reliability of this magnetic-core memory are now available in the new Univac Scientific Models 1103A and 1103B.

For the latest information about the Remington Rand magnetic-core memories or about the Univac Scientific, write, on your business letterhead, to...

Electronic Computer Department, Room 1641 **Remington Rand** 315 Fourth Avenue, New York 10, New York

Punch Press Output Up 30% with Speed-Trols at Square D Co.

Replacement of single speed motors with Speed-Trol variable speed drives on punch presses at the Los Angeles factory of Square D Company resulted in the following advantages, reports L. G. Maechtlen, Vice President: production increased 30% . . . spoilage or rejects reduced 10% . . . presses adapted to 40% more jobs . . . 100% synchronization of punch press speed and operator's ability . . . employee morale greatly improved.

STERLING SPEED-TROL

GIVES YOU VARIABLE SPEED CONTROL NECESSARY FOR:

Equipment adaptation to: Sequence synchronization — operators' abilities — load variations due to differences in quantity, quality, weight, size, tension, hardness or shape of material to be processed, machined, conveyed, blended, mixed, etc.

Process control of: Temperature—viscosity—level—pressure—flow—etc.

Time control of: Baking—drying—heating—cooking—pasteurizing—soaking—chemical action—etc.

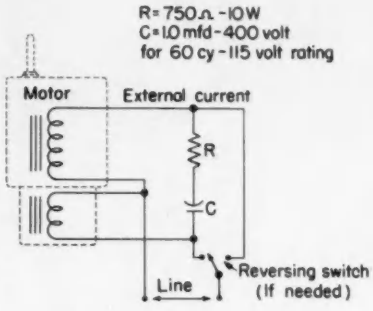
With Speed-Trol you get the maximum in production, plant efficiency, quality & profit.

20-page illustrated catalog . . . Sterling Speed-Trol, Slo-Speed, Klosd and Klosd-Tite Electric Power Drives. Write for catalog No. 205.

STERLING ELECTRIC MOTORS

Plants: New York City 51; Chicago 35; Los Angeles 22; Hamilton, Canada; Santiago, Chile Offices and distributors in all principal cities

NEW PRODUCTS



REVERSIBLE MOTOR tucks big torque in small frame.

The Bristol Series 430 Reversible Synchronous Motor develops three times as much torque as other low-priced hysteresis motors. Positive reversibility, high starting and synchronous torque, and small (2 in. cube) size make it adaptable to inexpensive remote control uses. Speed ranges from 1,800 rpm to 10 rph. For intermittent or short life use torque up to 5 in.-lb. can be handled. External phase shifting shown is recommended. *Vocaline Co. of America, Inc., Bristol Motor Div., Old Saybrook, Conn.*

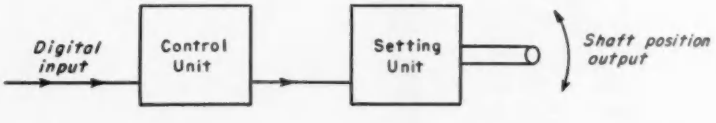
Circle No. 13 on reply card

CLUTCH BRAKE halts and hurries instantly.

Electro-magnetic actuation of this miniature clutch or clutch-brake results in power pick-ups or stops in a matter of milliseconds. Energizing a coil engages the clutch. Braking, if desired, can be provided at disengagement, which is effected by deenergizing the coil. Action can be remotely controlled by vacuum tubes and relays. Standard coil voltage is 28 vdc, with optional variations. *Globe Industries, Inc., 1784 Stanley Ave., Dayton 4, Ohio.*

Circle No. 14 on reply card

DIGITAL DEVICES AND PRODUCTS



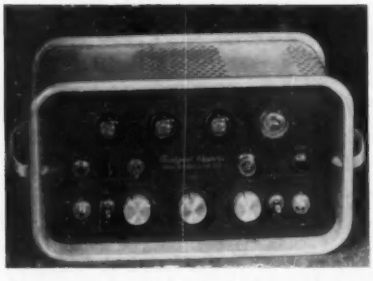
DIGITAL INPUT converts any arithmetic code to analog output.

This new device controls the angular position of a shaft from digital input. With typical speeds of 3,000 increments per sec and unlimited accuracy, it will position plotting board coordinates from a computer output, set machine tool dimensions through a lead screw or dividing head, and remotely set analog computer inputs, chemical flow valves, process control set points, or test equipment. No translator is required for any arithmetic code, and input consists of contact closures representing digital quantities. These contacts carry 1 ma from the Microsetter's power supply and may be manual switches, card or tape readers, or relays. They remain stationary during each setting operation. The unit then positions an output shaft to any number, or fraction, of revolutions specified by the input. Speed, input and output power, size, and applicability appear extremely versatile. The Microsetter has no memory element or pulse cumulator, so that if current from the control source fails, and then starts again, the Microsetter will move to the position dictated by the control unit, regardless of intervening changes. *Schatzki Engineering Company, 147-47 Springfield Lane, Springfield Gardens, Long Island, N. Y.*

Circle No. 15 on reply card

TIME, COUNT, and frequency in a shoe-sized box.

Combining the functions of frequency standard, interval timer, and electronic counter, the WE-210 indicates time to 0.0001 sec through 4 glow tubes. Ranges of 1 and 10 sec are possible but longer intervals can be counted visually or through an external electro-mechanical counter.



As a counter, it registers a maximum of 50,000 pulses per sec. Its built-in crystal-controlled oscillator provides 1 or 10 kc through front-panel outlets when the instrument is used as a frequency standard. Size 6 by 6 by 11 in. *Westport Industries, 149 Louita, El Segundo, Calif.*

Circle No. 16 on reply card

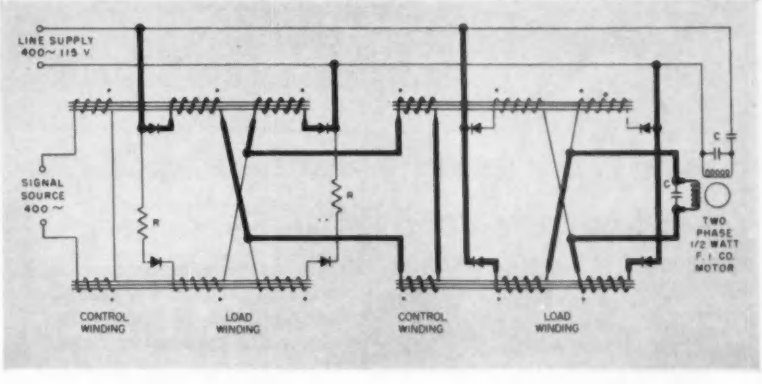
COUNTER complete with power and shaper.

This functional looking unit employs one 30 kc counter and four 10 kc decades. It has a built-in pulse-shaper and power supply for 117 ac operation. Using a dc source delivering from 6 to 50 for input, the shaper circuit functions to provide a coun-

SINCE 1915 LEADERS IN AUTOMATIC CONTROL

HALF-WAVE FAST RESPONSE MAGNETIC AMPLIFIER CIRCUITS

An important requisite of any practical amplifier is that it should be possible to cascade several units if more amplification is required than a single stage can offer. In usual magnetic amplifiers, this creates some practical difficulties because the inherently long time constants of each stage add up, and the cumulative time constant of the several stages may become excessive for practical applications.



Ford Instrument Company has perfected and holds the basic patents on circuits which allow cascading magnetic amplifiers with stages operating on successive half-cycles of the a-c supply.

In the circuit shown here, amplification in each stage of the amplifier is accomplished by pre-setting the core fluxes with the control-winding signal during one half-cycle of the applied load-winding voltage. During the next half-cycle, when the load-winding conducts, the control winding contribution is negligible. In this mode of operation the control winding of each stage of the amplifier receives its signal during the reset or non-conducting half-cycle of that stage of amplification. The effect of this signal occurs during the next half-cycle, thus the time constant in the stage is at a minimum of ½ cycle.

The amplifier uses half as many elements (cores and rectifiers) as the conventional bridge (full-wave circuit), and has a constantly higher figure of merit (power gain per cycle of time constant).

In amplification problems it will pay you to talk to the engineers of Ford Instrument Company. For forty years this company has specialized in designing and manufacturing special computers and controls. Send your problem to Ford.

57

FORD INSTRUMENT COMPANY
DIVISION OF THE SPERRY CORPORATION
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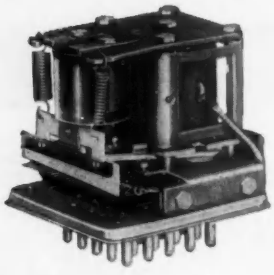
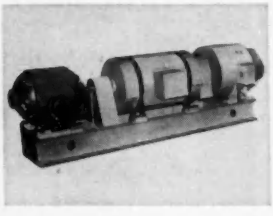
ENGINEERS
of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.



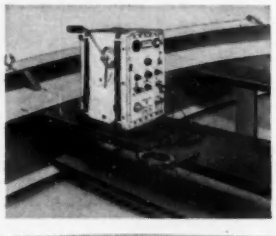
Practical design engineers prefer REGOHM Regulators...

On Land... Continuous Power Generating Systems



REGOHM regulates the output voltage of this 5KW generating system within a 4% band, independent of load changes and other operating conditions. Used to power control and communications systems, these units must operate every hour of the year. REGOHM's long life and plug-in feature that simplifies replacement makes it a natural for this application.

On Sea... Hand-Cranked Generators



Fast-acting REGOHM maintains constant output voltage on hand-cranked generators powering portable lifeboat radios. Reliable over a wide temperature range, independent of speed of rotation and output loading, REGOHM delivers radio noise-free performance under severe operating conditions. No other equipment equals its size, and low cost advantages.

In the Air... Control Instrumentation

REGOHM regulates voltage of special control instrumentation in pilotless bombers where precise, reliable control is a *must*. A two-inch cube, weighing under a pound, REGOHM economizes on space and weight. System stabilization is assured by its built-in dashpot, adjustable to match the system's dynamic characteristics. No anti-hunt networks are needed.

Whether your equipment or control system operates on land, sea or in the air ...involves power supplies or communications and signal systems, instrumentation or lighting systems...look into the advantages of REGOHM regulation.

REGOHM

Contact Electric Regulator Corporation, 120 Pearl St., Norwalk, Conn. Our Engineering staff will help you design required circuitry...recommend the proper REGOHM type...calculate the resistor network...suggest design modifications for optimum performance...analyze final designs...assist in testing pre-production models...service your requirements. Write or call us today.

Electric Regulator Corporation
Norwalk, Connecticut **Temple 8-4311**

NEW PRODUCTS

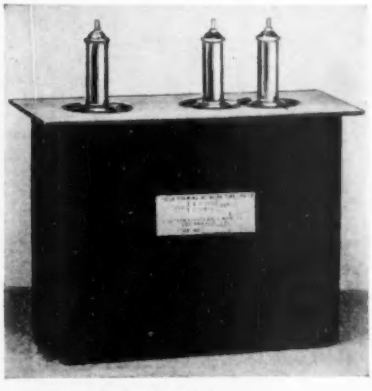
ter for industrial or laboratory component or test use. *Ransom Research, P.O. Box 382, San Pedro, Calif.*

Circle No. 17 on reply card

PULSE TRANSFORMER insulated with Epoxy resin.

A Gudeman 75 microsec two winding pulse transformer which is Epoxy resin impregnated and hermetically sealed sports the following: rise time-2 microsec, size-$\frac{7}{8}$ by $\frac{7}{8}$ by $1\frac{1}{8}$ in., and temperature range minus 70 to plus 135 C. *Gudeman of California, Inc., 9200 Exposition Boulevard, Los Angeles 34, Calif.*

Circle No. 18 on reply card



PULSE PRODUCER puts limits on pips.

Pulses with precision parameters are the output of this new item. A high-power pulse forming network, it specifies pulse duration, amplitude, voltage, and impedance in systems with 5 to 100 kv, 2 ohm or more impedance, and pulse width of 0.1 microsec. It's been tested for airborne ruggedness. *Luther Electronics Co.,*

5728 W. Washington Boulevard, Los Angeles, Calif.

Characteristics:

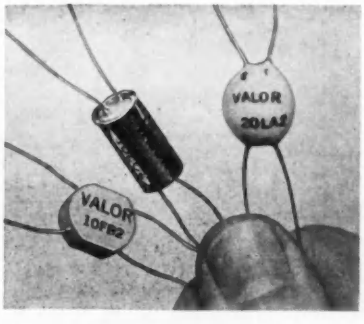
Size..... about 3 in. wide, 7 deep, 8 long.
Charging voltage 15 kv.
Duration of pulse 0.5 and 2.4 microsec.
Repetition rate. 2,000 pulses per sec.
Impedance..... 50 ohms
Weight..... 11 lb.

Circle No. 19 on reply card

ANALOG TO DIGITAL with radar-type circuits.

Readings as frequent as 20 three digit numbers per sec can be made with the Model 310 Digital Voltmeter, which employs radar-type measuring circuits. Range of measurement covers 100 milliv to 999 v, accurate to one digit. *Franklin Electronics, Inc., Philadelphia 40, Pa.*

Circle No. 20 on reply card



PULSE PASSER styled to suit the need.

Blocking transformers developing pulse widths from 0.1 to 8 microsecs and high-Q pulse coupling transformers of 0.1 to 10 millihenry inductance are in a new "F" series of ferrite core and "L" series ribbon steel core mod-

All Process Temperatures Now Recorded on One Chart at Low Cost

FACTS ABOUT THE FIELDEN MULTI-POINT RECORDER

- Records on one chart as many as 6, 24, 48 or even 96 points of temperature, pressure, level, pH, conductivity, speed, etc.
- Can be provided with control function having a single point or individually controlled points.
- Provides easy readability with 6 different color traces in each segment of the chart.
- High-speed recording—5 seconds per point.

Many process plants are now finding that they can accurately record all process temperatures or other variables of the same kind on one Fielden MULTI-POINT Recorder at a new low in cost per point.

Results in numerous applications show that Fielden MULTI-POINT Recorder not only provides all the accuracy needed for most processes (±0.5%), but its high speed insures quick warning of any upsets. In addition, the instrument's simplified design enables plant personnel to handle any maintenance. These design features provide big savings in initial and operating costs.

Send the coupon today, and learn how *Fielden Simplified Instrumentation* can solve your problems too . . . dependably *and* economically.

Robertshaw-Fulton
CONTROLS COMPANY

FIELDEN INSTRUMENT DIVISION
Dept. S, 2920 N. 4th St., Philadelphia 33, Pa.

Please send me bulletins describing:
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☐ TEKTOLOG Recorder-Controller
☐ TEKTOR Level Limit Control
☐ NULL-BALANCE Recorder-Controller
☐ TELSTOR Continuous Level Indicator

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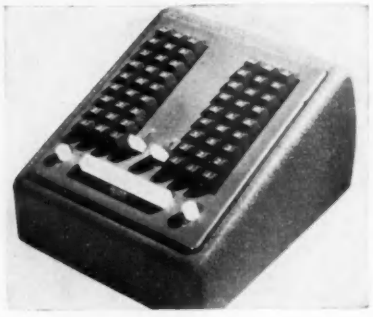
3349 ADDISON STREET
CHICAGO 18, ILLINOIS

RELAYS • SOLENOIDS • COILS • TRANSFORMERS • SWITCHES • HERMETIC SEALING

NEW PRODUCTS

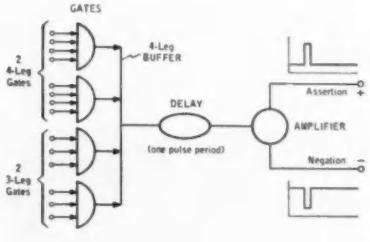
els. As coupling transformers, the ferrite units have rise times in excess of 0.005 microsecs. Both types are obtainable in Epoxy excapsulated, molded and hermetically sealed metal cases with 2 and 3 windings, made to military specs. *Valor Electronics Components Co., 5808 Marilyn Avenue, Culver City, Calif.*

Circle No. 21 on reply card



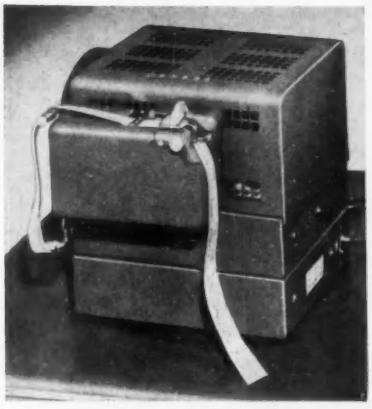
KEYBOARD VOLTAGES fed in plotter provide X-Y points.

For the manual conversion of data into X-Y voltages, three banks of precision resistors are connected to the keys of this keyboard through wiper contacts aimed at low-contact resistance without sticking. Connected to an X-Y plotter, the punched-in values of X and Y are transformed into voltages that drive the pen mechanism to the appropriate point, where-



upon the pen lowers and marks a dot. Quadrant location of the point, positive or negative, is achieved by switches on the face of the keyboard, which reverse the connections of the input power, normally taken directly from the associated plotter. Librascope makes two models and a punched card converter system, too. *Librascope, Inc., Glendale, Calif.*

Circle No. 22 on reply card



PUNCHED-TAPE for dexterous data delivery.

Although shown separate above, the two machines interconnect to work together.

Postings performed on Auto-Punch Bookkeeping Machine are duplicated in perforated tape for use in other tape-programmed office machines, Tape errors can be corrected instantly. An inter-lock prevents key misoperation. Punching speed is 20 digits per sec. Auto-Punch Adding Machine perforates and codes in 5, 6, 7 or 8-channel tape and, like the bookkeeping machine, features automatic error correction. Tape is punched at a speed of 1,800 digits per min. *Monroe Calculating Machine Co., Orange, N. J.*

Circle No. 23 on reply card

FEEDBACK FACT

Posed: Revolving doors to suit the cautious and cantankerous.

Solved: International Steel Co. offers two-speed automatic revolvers which will guide a totterer at 3 rpm, delight a tot at 12 rpm.

vernistat... *The Revolutionary New Precision Variable-Ratio Transformer*

Analog Computers? Servos? Control Systems? Vernistat is a completely different type of voltage divider combining **low output impedance with an inherently high resolution and linearity** not ordinarily attainable by precision potentiometers.

The Vernistat consists of a tapped auto-transformer which provides the basic division of voltage into several discrete levels. These levels are selected and further sub-divided by a continuous interpolating potentiometer that moves between 30 transformer taps.

Because of its unique operating principles, electrical rotation is held to close tolerances eliminating the need for trim resistors. In many applications there is also no need for impedance matching amplifiers.

Specifications of the standard model Vernistat are shown below. Other versions are under development to meet specific end uses.

What are your requirements for this unique precision voltage divider? Fill in the coupon now.

vernistat division PERKIN-ELMER CORPORATION
NORWALK, CONNECTICUT

SPECIFICATIONS

Linearity Tolerance	better than ±.05%
Resolution	better than .01%
Output Impedance	130 ohms (max.)
Max. Output Current	50 ma
Frequency	50-3000 cps

Other models including a miniaturized 400 cps version will be available in the near future.

vernistat division PERKIN-ELMER CORPORATION
815 Main Avenue, Norwalk, Connecticut

Send me more information on the Vernistat.
The application I have in mind is as follows:

NAME

TITLE

COMPANY

ADDRESS

LOW MAINTENANCE
HIGH PERFORMANCE
PUMPING

"K" type pump handling concentrated mixture containing high proportion of free sulfuric acid.

HILLS-McCANNA "K" type HYDRAULIC metering and proportioning pump

In the Hills-McCanna "K" pump, a unique, in-line, direct acting hydraulic drive system eliminates familiar pump problems of exposed linkage, linkage lubrication, atmospheric effects . . . linkage and drive misalignments. Maximum reliability and performance with a minimum of maintenance is assured.

But there's more . . .

A wide choice in corrosion, wear and abrasion-resistant liquid ends gives the "K" pump a broad application range . . . it will meter and proportion virtually any fluid.

If you refine, process, handle or just *pump* problem fluids, it will pay you to remember that the Hills-McCanna "K" pump is available in one and two feed units in capacities up to 726 gph per feed.

Write for Bulletin KP54, HILLS-McCANNA CO., 2400 W. Nelson St., Chicago 18, Illinois.

COMPLETELY ENCLOSED

ADJUSTABLE WHILE IN OPERATION

OPERATES IN OIL

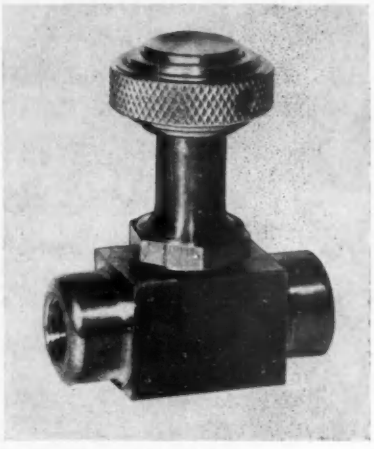
BUILT-IN PRESSURE RELIEF

HILLS-McCANNA

metering and proportioning pumps

Also Manufacturers of:
SAUNDERS TYPE DIAPHRAGM VALVES
FORCE FEED LUBRICATORS • MAGNESIUM ALLOY SAND CASTINGS

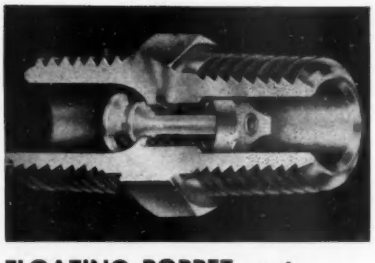
VALVES FOR CONTROL



TEFLON SEAT defies over-torquing.

This metering valve is said to provide positive finger-tip control in water manometer installation under line pressure of 2,500 psi. Since the metering pin and buffer plate act as a forming die against the Teflon seat, over-torquing damage is inconsequential. The hand wheel turns freely through a leak-proof double "O" ring assembly at all pressures. The valve may be applied to both gases and liquids at minus 110 to plus 500 deg F and is supplied in ⅛ in. pipe thread size. *Robbins and Associates, 1735 W. Florence Ave., Los Angeles 47, Calif.*

Circle No. 24 on reply card

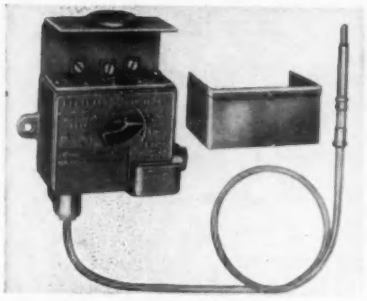


FLOATING POPPET seats sanely, securely.

The "floating poppet" design of this 0-10,000 psi check valve (Circle Seal 2300) protects its spherical seat from "wire drawing." The one-piece body and "O" ring are available in several material combinations for

versatile high-pressure application. *James-Pond-Clark, 2181 E. Foothill Blvd., Pasadena 8, Calif.*

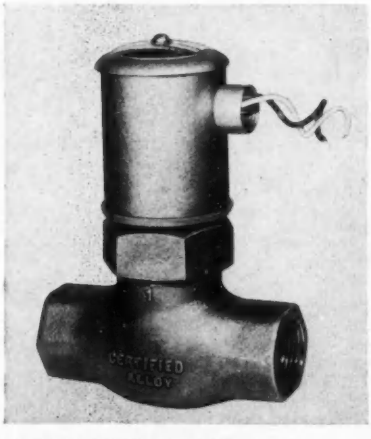
Circle No. 25 on reply card



SAFETY SHUTOFF reset by knob.

100 per cent shutoff is obtained by this reset relay when used with an electric main line valve and a pilot valve on gas-fired appliances. The A-100 rotary reset thermopilot relay gives visual assurance of safe lighting conditions. *General Controls Co., Glendale, Calif.*

Circle No. 26 on reply card



SOLENOID VALVES waste little motion.

There are just three moving parts —piston, pilot valve and spring—in this Type K solenoid valve with unconditionally guaranteed coils. Coils for temperatures to 250 deg F are waterproof molded. For higher temperatures they are glass insulated and silicone impregnated. Other features: piston-pilot valve operation, packless chamber, cushioned closing and tight-seating. Parts in contact with the media are of stainless steel. *J. D. Gould Co., 730 E. Washington St., Indianapolis, Ind.*

Circle No. 27 on reply card

Attention: Executive in charge of getting the **JOB DONE!**

Magnetic Amplifiers · INC

AFFILIATE OF GENERAL CERAMICS CORPORATION

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For Application on Commercial and Military:

Aircraft **Machine Tools**
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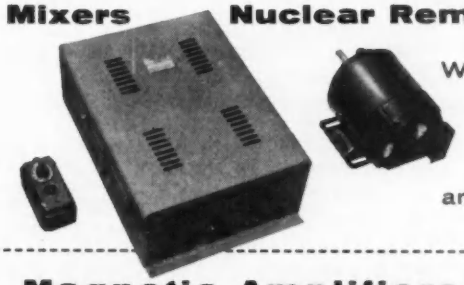

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PRESET COUNTERS

Automatically count and control to 1,000,000 events.

Model DS-8600 Series (5 Models)

Designed to control any operation after a preselected total count has been reached. Used to count pills, bottles, cans, machine parts, etc. for automatic packaging.

If an event can be converted to an electrical impulse—it can be counted and controlled with a Detectron Preset Counter.

Dual models available which provide output signals at any two preset totals. Write for catalog or contact nearest representative.

FEATURES
- Absolute Accuracy
- High Speed
- Reliable
- Automatic
- Rugged
- Economical
- Small Size

SPECIFICATIONS	DS-8602	DS-8603	DS-8604	DS-8605	DS-8606
Decades	2	3	4	5	6
Count Capacity	100	1000	10,000	100,000	1,000,000
Counts Per Second	0-100,000				
Input Sensitivity	0-10 counts per second: 1 volt RMS 10-20 counts per second: 0.5 volt RMS 20-100,000 counts per second: 0.1 volt RMS				
Input Impedance	1 megohm., 0.05 mf.				
Output Signal	50 volt positive pulse				
Recycling Rate	35,000 per second				
Relay Hold Time	Automatic: 0.01 to 0.1 seconds 0.1 to 1.0 seconds 1.0 to 10 seconds			Manual: Until reset	
Power Requirements	117 volts ± 10%, 50-60 cycles				

Write Dept. 84-F

Detectron* Computer-Measurements Div.

*Trade Mark

THE DETECTRON CORP.
5528 Vineland Ave., North Hollywood, California

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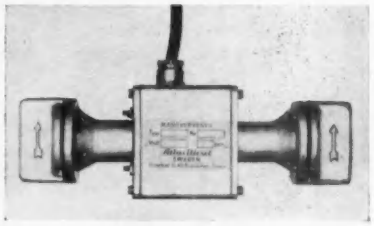
CANADA
Electromechanical Products
Agincourt, Ontario. 493-R-2

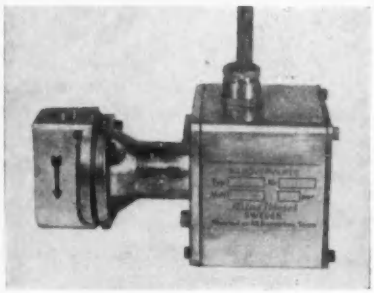
EXPORT
Frazar & Hansen, Ltd.
301 Clay St., San Francisco, Calif.

NEW PRODUCTS



SWEDISH PAIR triggers electromagnetically.

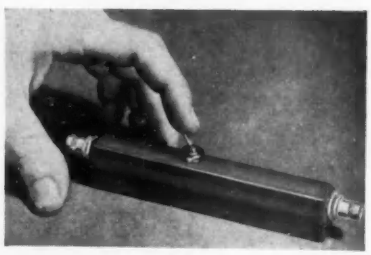
From Sweden come two electromagnetic valves for remote air line pressure control from 21-85 psi. The single valve is available in $\frac{3}{8}$ and $\frac{1}{2}$ in.



port sizes, the double in $\frac{3}{8}$ in. port size only. Reciprocal action of the double valve simultaneously opens one air line and closes another. When the current is off, one valve is held normally closed, the other normally open by a return spring. Both models resist corrosion. Power from ac or dc 6, 12, 24, 48, 110 or 220 v can be handled. *Aktiebolaget Atlas Diesel, Stockholm, Sweden.*

Circle No. 28 on reply card

POWERING PRODUCTS

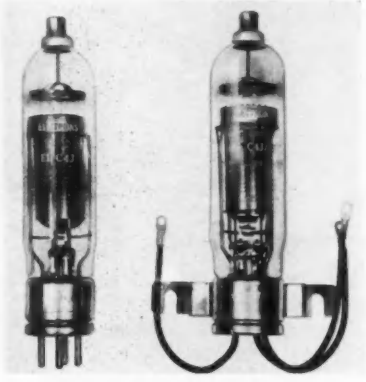


STREAMLINE PREAMP handles near-nonexistents.

Credit Du Mont for the neatest trick of the month. Here's a preamplifier with a self-contained power

supply packed so cleanly that it's hardly more than a bulge between its input and output cables. Amplifying a billionth of a watt signal at a microvolt level, its transistorized circuitry produces an output 1,000 times more vigorous, with virtually no noise. Battery life is 1,000 hours. Not only is a big market for the little machine seen in the medical field, but it is likely to be in demand as a supersensitive strain gage pickup system. *Allen B. Du Mont Laboratories, Inc., Technical Sales Dept., 760 Bloomfield Avenue, Clifton, N. J.*

Circle No. 29 on reply card



TWO THYRATRONS fit socket or panel.

A pair of electrically-identical Xenon-filled thyratrons are offered for motor control and ignitor firing circuits. The ELC4J, for socket, and the ELC4J/F, for panel mountings, are rated at 4 amp dc with 30 amp oscillograph peak and maximum forward and reverse peak of 900 v. Average arc drop is 12 v, heating time is 60 sec and critical grid current is less than 10 ma. *Electrons, Inc.*, 127 Sussex Ave., Newark 4, N. Y.

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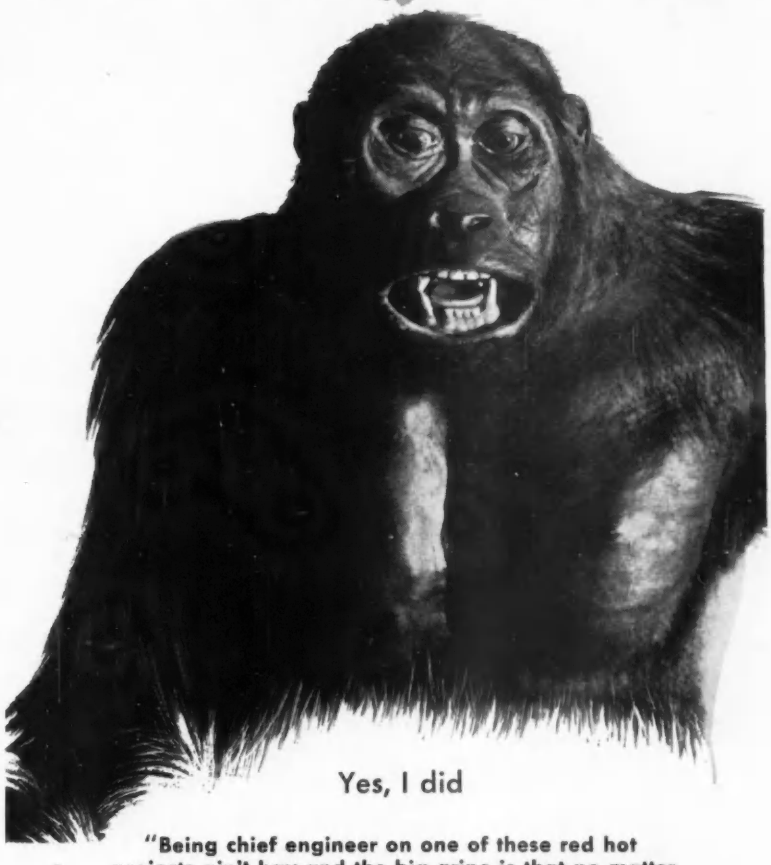
MAGNETIC REGULATOR serves M-G sets.

The small (3½ x 10 x 10 in.) but rugged Magnetic Type Voltage Regulator combines with a 400 cycle alternator for both synchronous or induction motors up to 30 kw. It regulates the field of a rotary exciter with a rated maximum output of 80 watts. Adjustment range is within 10 per cent with 115 v. It can be furnished for any voltage and regulation is within 1 per cent. Hermetic sealing

I tol 'em and I tol 'em!



Yes, I did

"Being chief engineer on one of these red hot projects ain't hay and the big gripe is that no matter what goes wrong I can't fix it. That's why at the start when the confusion is still gently confined to the breadboard you should call in Sigma. Confusion is an old story to those boys." — *actual unsolicited testimonial by I. M. A. Ape, Sc. D., chief engineer, Simian Products Company, Kivu Heights, Africa.*

OK, now that you've had the hard-sell, we do have a relay that we'd like to talk about. It does some difficult jobs very well. Here are the basic specifications:

SIGMA SERIES 22

Miniature (not sub-miniature) sensitive double pole sensitive relay. Excellent combination of small size and high performance.

Sensitivity . . . SPDT: 20 milliwatts (e.g., with 8000 ohm coil, operate 1.6 ma.) DPDT: 40 milliwatts (e.g., with 8000 ohm coil, operate 2.3 ma.)

Contact Rating . . . 2 amp., 115 V AC or 28 V DC, 100,000 operations

Vibration . . . 10 g from 10-2000 cps

Shock and Acceleration . . . 100 g non-operating

50 g operating with additional margin

Size . . . 22RJ: 1" square x 1¾" high 22RJ2, 22KN: 1" square x 2" high

Weight . . . 3 ounces max.

If you are interested, we'll be glad to send you a bulletin sheet on the Series 22, or a complete catalog if you prefer.

SIGMA

SIGMA INSTRUMENTS, INC.
69 Pearl St., S. Braintree, Boston 85, Mass.

Design for Low Control Cost...

ARENS "Seven Standards" may help you save money.

ARENS PUSH-PULL CONTROLS

Low in price, easy to install, there are seven standard Arens designs to meet light, medium and heavy load requirements. They are available with a variety of control heads, casings, and end fittings. Special controls can also be designed to meet specific requirements. Design with Arens Controls in mind . . . and save.

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CURTIS
Types "M" & "MT"
Build-up Terminal Block Kits

Type "MT"

Type "M"

You Build Them to Your Needs

Write for Bulletin DS-122. Also, ask about wide selection of other Curtis Blocks available.

Both the "M" and "MT" Blocks built from these kits are identical to the factory assembled blocks of the same types. The only difference between the "M" and "MT" kits is the marking tag for circuit identification provided with the "MT" kit. They have been put in kit form to save you time on engineering, research, maintenance and repair work. They can be assembled in blocks of 2, 3, 4, 5, 6, 8, 10 and 12 terminals from the parts furnished. Rated 300 volts, 15 amperes.

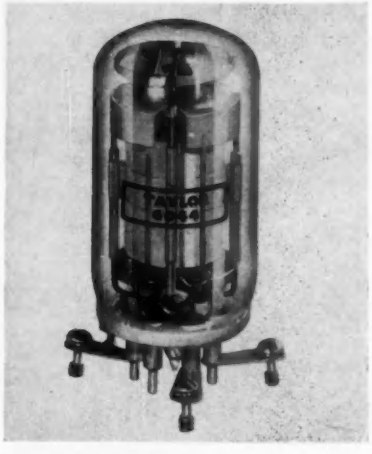
CURTIS DEVELOPMENT & MFG. CO.

3258 North 33rd Street, Milwaukee 16, Wisconsin

NEW PRODUCTS

permits difficult operations in adverse conditions through a minus 60 to plus 71 deg ambient range. *Magnetic Instrument Co., 82 Main St., West Orange, N. J.*

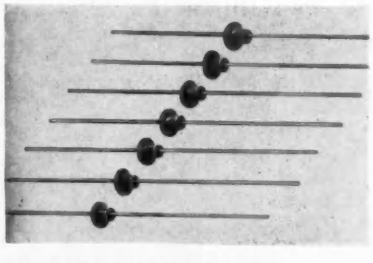
Circle No. 31 on reply card



RECTIFIES with brief dionization time.

Model 6044 Xenon Thyratron is especially suited for short dionization time or high peak current carrying capacity applications. Simplified rigid mounting eliminates sockets and ambient range is from minus 65 to plus 85 deg C. Filament operates at 2.5 v, 17 amp. *Taylor Tubes, Inc., 2312 W. Wabansia Ave., Chicago 47, Ill.*

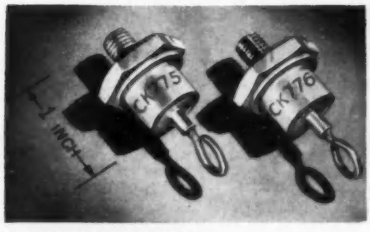
Circle No. 32 on reply card



SILICON RECTIFIERS have low forward drop.

This new line of Silicon Power Rectifiers is rated from 100 to 500 milliamps. Hermetically sealed 0.1 oz units operate at high ambient range with low voltage drop and minimal reverse leakage. Maximum forward drop at full rating is less than 2 v with blocking voltages from 50 to 500 v in standard, and up to 1,000 v in special units. *Bogue Electric Mfg. Co., Paterson, N. J.*

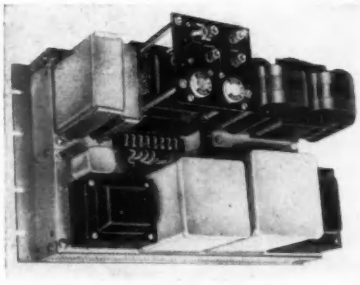
Circle No. 33 on reply card



PETITE SILICONS rectify powerfully.

Two silicon power rectifiers, types CK 775 and CK 776, can handle 15 amp and 200 peak voltage with permissible operation at 5 amp and 170 deg C. Reverse to forward resistance ratio is 1 to 100,000 for these hermetically sealed midgets (0.6 cubic in.). *Raytheon Mfg. Co., 55 Chapel St., Newton 58, Mass.*

Circle No. 34 on reply card



TUBELESS REGULATOR withstands vibration.

Here's an automatic voltage regulator that can pass through full range (95 to 135 v) in less than one sec. Operating without tubes or moving parts, it holds output voltage to within one volt band. From rack or cabinet it oversees microwave or other installations where a voltage regulator cannot easily be attended or where vibration would break electronic tubes. Maximum frequency range is 55 to 65 cps and waveform distortion is limited to 3 per cent. *The Superior Electric Co., Bristol, Conn.*

Circle No. 35 on reply card

FLUX manipulator drives servos.

The PRD T6C16W1 Saturable Transformer will drive 115 v, 60 cps servo motors requiring 16 watts to the control phase. Employing magnetic components, unit gives low-drift service through a minus 55 to plus 85 deg C ambient range. Band-

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REMOTE CONTROL
of your entire plant operation
...at your fingertips!

NEW
TALLER & COOPER
TELEMETERING SYSTEM

supervises multiple functions with only 2 wires!

NEVER BEFORE such a simplified method of telemetering! Over a single pair of wires, multiple control of great numbers of functions is possible. The unit is rugged, compact, economical to run—an ultra reliable machine that affords complete plant control with the push of a button or switch.

Write for detailed specifications.

This new telemetering system supervises the control of 10, 16, 20 or 32 plant operations instantaneously!

Combinations of these units can increase control to 100, 250 or even more functions, if needed.

Push button or switch control operates valves, pumps, motors, switches, fans, signals, etc.

- Control Equipment & Systems
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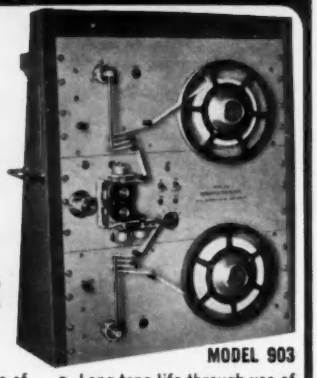
PERFORATED TAPE READER

with take-up reels



MODEL 903

- Character Reading Speeds of 600, 300 or 150 per second.
- Five millisec start time.
- Simple Photo-Diode Reading Head.
- Bi-directional.
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- Reads 5, 6, 7 or 8 level perforated tape.
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NEW PRODUCTS

width is 0 to 3 cps with a power gain of 20. Hermetically sealed in an MIL type can, it operates with a simple vacuum tube voltage preamp. *Polytechnic Research & Development Co., 202 Tillary St., Brooklyn, N. Y.*

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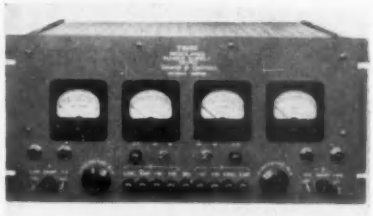
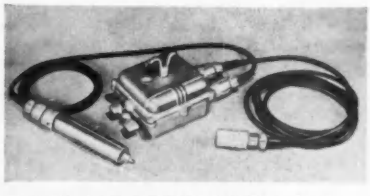


LAB PRECISION voltages for transistors.

Especially for transistor development, the TR-200AT supplies 0-10 and 0-100 vdc output regulated to better than 0.1 per cent for plus or minus 10 per cent line variation. Two voltmeters and two ammeters serve each output range and two other 6.3 vac, 8 amp outputs extend its application. *Universal Electronics Co., 2012 S. Sepulveda Blvd., Los Angeles 25, Calif.*

Circle No. 37 on reply card

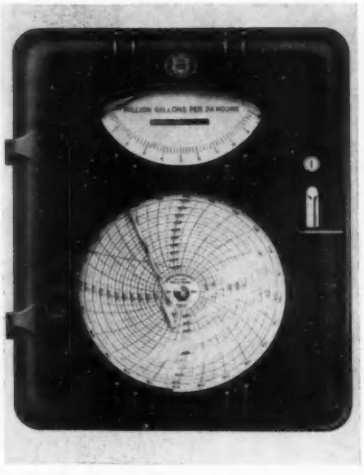
WAYS TO MEASURE



PRESSURE REGULATOR claims super simplicity.

This little set, said to be one-quarter the size of anything comparable, is for pressure regulation of pneumatic or hydraulic systems. The pickup uses a pair of cadmium plated steel springs and a brass piston. The unit withstands pressures of over 3,000 lb. and will provide control in the ounce range. It retails for about $15. *Beacon Devices, Inc., 78 Oliver Street, North Tonawanda, N. Y.*

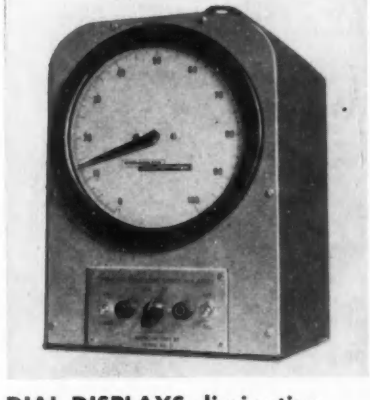
Circle No. 38 on reply card



RECEIVES DATA
over two-wire circuits.

Orthoflow is used in the transmission of flow, level and pressure data to remote location through a two-wire circuit. It may be applied to mercury cylinders to transmit measurements over 4, 10, 13, 18.5 and 20 to 1 ratios with accuracies of within 2 per cent. Explosion proof construction makes it suitable for critical location. *Simplex Valve & Meter Co., 7 E. Orange St., Lancaster, Pa.*

Circle No. 39 on reply card



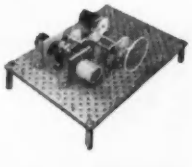
DIAL DISPLAYS diminutive displacements.

Using an external linear variable differential transformer (LVDT), this machine not only provides motion indication for distances as small as .00005, but yields limit switch performance as well. A two-position switch below the 7 in. diam dial allows choice of sensitivity and zeroing at any time. This is really a LVDT bridge, an internal LVDT being

What's Your Angle?

says she . . . WHAT ANGLE? says he . . . EVERYONE'S GOT AN ANGLE . . . says she . . . and SERVO HAS DEVELOPED A LINE OF EQUIPMENT TO MEET YOUR NEEDS NO MATTER WHAT YOUR ANGLE!

IF IT'S YOUR PHASE ANGLES that need analyzing, the **SERVOSCOPE*** will accurately and rapidly measure them. Just a few turns of the dial will give you the values for plotting magnitude and phase curves. The **SERVOSCOPE** generates modulated carrier, low frequency sine, and square waves. So, whether you're developing new designs or de-bugging production testing, let **SERVOSCOPE**, the only equipment of its kind, save you man-hours and prevent costly errors.



IF IT'S DESIGN ANGLES — the **SERVOBOARD*** provides a flexible experimental electromechanical assembly that allows you to mock-up your intended designs and test them. No longer must you wait for an overloaded breadboard shop to come through. Developed as an aid to the design of servomechanisms and computers, the **SERVOBOARD** will quickly provide the standard precision parts needed to set a preliminary design into mechanical form.

IF IT'S AZIMUTH ANGLES for direction finding, **SERVO's VHF Receiver** will do the job. Its directly calibrated 72" bandspread dial speedily locates the frequency region of interest. This precision constructed receiver provides all custom features needed for communication and laboratory work. In addition, special outputs are provided for the receiver to be used as a component in complete communication, telemetering or direction finding systems.

SERVO's PRECISION CONSTRUCTED EQUIPMENT IS AN EXAMPLE OF SOUND ENGINEERING AND UNEXCELLED CRAFTSMANSHIP. BEHIND SERVO PRODUCTS STANDS A RECORD OF OUTSTANDING PRACTICAL ENGINEERING ACHIEVEMENTS.

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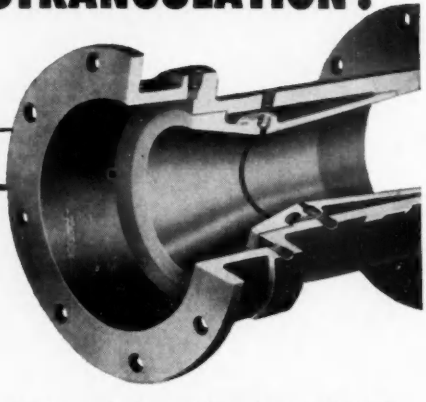

Builders Dall Flow Tube reduces meter head loss where it counts . . . . at the pipe line!

Here's what you can gain by replacing orifice plates with Dall Flow Tubes in your pipe lines: You reduce pumping costs. You avoid the expense of purchasing over-sized pumping equipment. You gain adequate process flows without building new and costly piping layouts. With it, you obtain top repeatability and long life.

Builders Dall Flow Tube gives maximum pressure recovery — more than any other velocity increasing flow tube. It's compact and economical, too. For complete details, write for Bulletin 115-L1. Builders-Providence, Inc., 528 Harris Avenue, Providence 1, Rhode Island.

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BUILDERS IRON FOUNDRY • PROPORTIONEERS, INC. • OMEGA MACHINE CO. BIF METERS FEEDERS CONTROLS

NEW PRODUCTS

driven against the external one by means of a cam attached to the pointer. Special accessories are also available, including an analog-to-digital transmitter. *Schaevitz Engineering, Camden 1, N. J.*

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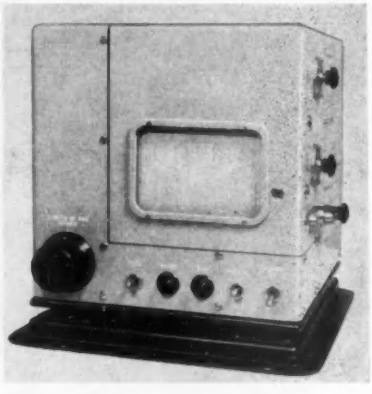
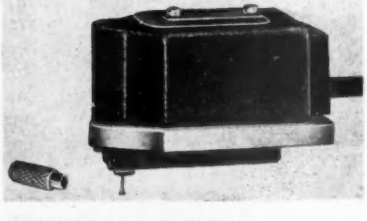


STYLUS RECORDER fixes 210 channels of info.

Using 5-in.-wide electro-sensitive paper, the R-1021-D Recorder will record analog, digital, or sequential data with 210 fixed styluses. Built to take vibration, temperature, and humidity, it will operate on 60 or 400 cycle 115 vac current. *Radiation, Inc., Melbourne, Fla.*

Circle No. 41 on reply card



CONVERTS SHIVERS to potentials

Roughly analogous to a magnetic phonograph pickup, this hand-held MB Type 115 vibration pickup is intended to convert surface vibration into electrical signals through the vibration of a coil suspended between two permanent magnets. Voltage output can be fed directly into a recorder, spectrum analyzer, or vibration meter for establishing vibration characteristics of machinery, aircraft, etc. *The MB Mfg. Co., Inc., New Haven 11, Conn.*

Circle No. 42 on reply card

DOUBLE-BURDENED bourdon trips two switches.

Two switches operate independently at successive or high and low temperature stages in this two-stage mercury temperature control. Heart of the unit is an actuating bourdon tube. Controls, which can be furnished in 11 operating ranges, have external shipments and a calibrated dial. The switches are available in general purpose, weather- and explosion-proof cases. *Mercoid Corp., 4201 Belmont Ave., Chicago 41, Ill.*

Circle No. 43 on reply card

CAPACITY CHANGES echo pressures.

This electronic pickup indicator, Model PM-121, measures pressures, acceleration, and displacement when used with Rutico transducers. A parallel resonant circuit responds to minute capacitance changes at high frequencies when pressure is applied at the diaphragm. It is designed for direct reading or for use with an oscilloscope and has a flat frequency response from dc to 300,000 cps within 2 db. *Rutico, Inc., 490 South Fair Oaks Avenue, Pasadena, Calif.*

Circle No. 44 on reply card

RELAYS AND SWITCHES

ELECTRONIC SWITCH shows traces a wisp apart.

With amplifier rise time of 0.023 microsec, Model ES-180 electronic switch is a natural for oscilloscope studies of two signals. It switches from one signal to the other at the end of each sweep with speeds of up to 100 kc. Through unity gain and

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INDUSTRY PROVED

RCA—pre-eminent in the design and development of phototubes—offers a comprehensive line of high-quality phototubes to meet your replacement needs in light-actuated devices. The line includes a wide selection of gas types (for sound-on-film and relay work)—vacuum types (for fast response and precision measurements)—and multiplier types (for applications where extremely high sensitivity is important, such as scintillation counting). RCA Phototubes are available in a variety of spectral responses, physical shapes, and sizes—from your RCA Tube Distributor. For tube technical data on RCA Phototubes, write RCA, Commercial Engineering, Section F56T Harrison, N. J.

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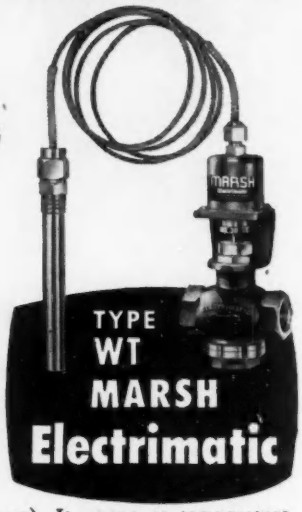
RADIO CORPORATION of AMERICA

ELECTRON TUBES **HARRISON, N.J.**

MARSH QUALITY

. . . in a Temperature-actuated

REGULATING VALVE



Smooth, modulating control

— for brine lines in cooling systems

— for condensers where pressure line is not desired

A temperature actuated regulating valve you can depend on—the Marsh Electrimatic Type WT for pressures up to 150 psi, water or brine, and up to 15 lbs. for steam (250° maximum temperature). It opens as temperature rises, closes as temperature falls, to give an ideal, smooth, modulated control. Can be mounted in any position; serviced without breaking connections. Seat beads are monel to eliminate wire drawing. Sturdy, two-ply bellows assures extra service life. Temperature ranges of 20°F.-60°F.; 60-100, 100-140, 140-180, 160-220. All standard sizes from ⅜" through 4". All styles of temperature bulbs.

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Marsh Instrument & Valve Co. (Canada) Ltd., 8407 103rd Street, Edmonton, Alberta, Canada

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Allows operation of auxiliary protective devices* after operating cycle is stopped. Easily installed in any electrical line.

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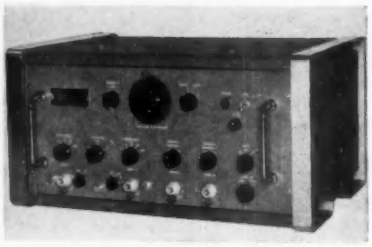

stabilized power supplies in the two amplifier channels, two signals can be compared in time to one millimicrosec. The switch responds to waveforms of either polarity. *Teletronics Laboratory, Inc., Westbury, L. I., N. Y.*

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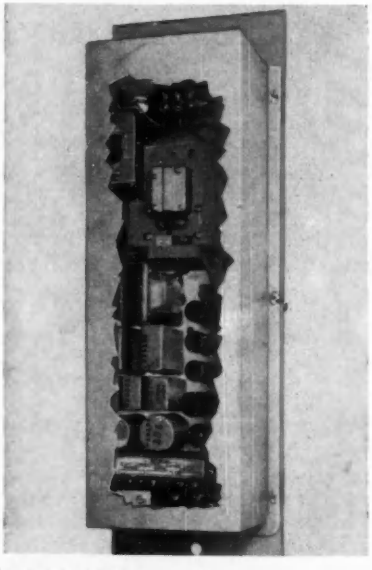

EMF TO PSI machine mates electronics to pneumatics.

The conversion of dc into air pressure is the objective of this package. A millivolt signal from a measuring element is converted into a proportional 2,000 cps ac voltage which then is amplified and filtered. The resulting dc output is used to position a flapper-nozzle assembly to provide an air relay output proportional to the original dc measurement signal. Input spans as small as 10 millivolts and as wide as 60 are available. Sensitivity of 0.05 per cent and accuracy of plus or minus 1 per cent of full scale are claimed. Complete response to a full-range step takes 4 sec or less. *The Foxboro Co., Foxboro, Mass.*

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(57) ELECTRONIC TIMERS. G. C. Wilson & Co. Brochure, 5 pp. Gives data on standard line, which includes delay, repeat cycle, and interval timers.

(58) COIL FORMS. Precision Paper Tube Co., Form 235-355, 4 pp. Covers square and round tubes, bobbins, coils made by the Resinite Div., and mandril and frabricating services. Precision calls itself the exclusive manufacturer of square and round tubes for the electronics industry.

(59) LB ANALYZER. Liston-Becker Instrument Co., Inc., 8 pp. H. R. Smith, editor of this new house quarterly, writes in the first issue that it is devoted to application and progress of infrared gas analyzers. This issue contains a reply card for the mailing list.

(60) COMPUTER DISPLAY TUBE. Hughes. Folder, 4 pp. Details of the Typotron, computer readout which can display any combination of 63 characters indefinitely and race through 25,000 per sec.

(61) PRECISION POTENTIOMETERS. Electro-Mec Laboratories, Inc. Folder, 4 pp. Gives characteristics of standard line, all featuring ultra-low torques, and points to availability of custom-engineered types.

(62) PRINTED WIRING. Aerovox Corp. Special Products Div. Form SP-542, 8 pp. Pure silver conductors, bound firmly but without adhesives to a paper-base phenolic, are sketched in this information-weighted booklet.

(63) DIGILOG COMPUTER. Wang Laboratories. Folder, 4 pp. Tells how this instrument combines the high accuracy of the digital computer with the simplicity of the analog. Available precision is five decimal digits.

(64) BROCHURE ON RELAYS. Potter & Brumfield Mfg. Co. Brochure, 70 pp. Contains 23 papers originally presented at the Third National Conference on Electromagnetic Relays at Oklahoma A&M College, Stillwater, in March.

(65) AIR TO TORQUE. U. S. Electrical Motors, Inc. Form F-1882, 8 pp. This attractive treated-paper booklet explains how the Aritrol uses a 3-15 psi pneumatic signal to control the speed of a Varidrive motor and equip it for use in a conventional continuous control system.

(66) LOAD CELLS, LOAD BEAMS. Baldwin-Lima-Hamilton Corp. Testing Equipment Dept. Bulletin 4301, 9 pp. Stresses the small deflection of load cells (0.010 in. maximum at full load) and absence of wearing parts in BHL units for electrical measurement of weight and force.

(67) THERMISTOR MANUAL. General Electric Co. Carboloy Dept. Manual TH-13, 54 pp. Here's a neat little text on the construction and applications of thermistors. Static and dynamic characteristics of Carboloy products are plotted according to type.

(68) RELAYS. Assembly Products, Inc. Bulletin 108. A succinct single-sheet rundown of specifications for relays and plug-in components. Some of the relay data are brand new. Bulletin G-8 condenses previous information on Simply-trol temperature controls.

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(69) SIDE INDICATOR METERS. International Instruments, Inc. Engineering Data Sheet. Treats specifications for horizontally and vertically mounted meters. Scale length exceeds standard dimensions and panel area is less than ½ standard.

(70) PNEUMATIC CONTROLLER. The Foxboro Co. Bulletin 5A-13, 12 pp. Features of this model, 41A, include a longer, more readable indicating scale, simplified maintenance, and adjustable proportioning action.

(71) MOTOR CATALOG. National Pneumatic Co., Holtzer-Cabot Motor Div. Bulletin MO-3.3. Covers special motors, motor generator sets and related products, and full range of frame sizes.

(72) TELEPHONE-TYPE STEPPING SWITCHES. Automatic Electric Co. Bulletin RH6. Illustrates the suitability of these switches for data reduction in computers. One application cited is use with the Berkeley digital recorder model 1452. Specific switch involved here is Type 44 rotary stepping switch.

(73) AIRBORNE FLOWMETER. Potter Aeronautical Co. Bulletin AF-1. Lists specifications of the three elements making up this small, panel-mounted instrument: flow senser, flow rate indicator and flow totalizer. Accuracy is within 1.5 percent of full scale.

(74) PUNCHED-CARD MACHINES. Remington Rand, Inc. Folder TM930, 6 pp. Gives lowdown on 25 machines that perform punched-card operations. Line includes punches, reproducers, computers, arrangers, and printers. Comparative versatility is charted.

(75) ELECTRO CLUTCH. I-T-E Circuit Breaker Co. Rectifier Div. Bulletin 5306, 14 pp. Sizes, ratings, applications, and theory are covered in this bulletin, in which I-T-E announces its introduction of this European clutch to U. S. industry. Its use in control equipment is discussed in 14-page pamphlet by H. B. Stallings of I-T-E.

(76) LIQUID-FILLED THERMO-SWITCH. Fenwal, Inc. Sheet MC-122. Gives specifications for this Series 2000 snap-action thermostat designed for controlling electrical loads up to 15 amp where a local bulb is required.

(77) DATA FROM BRISTOL. The Bristol Co. Bulletin P1260, 48 pp. This work on furnace and oven control instruments and accessories is in a new edition. So is Bulletin P1238, 56 pp., which deals with thermocouples and pyrometer accessories.

(78) VIBRATION CONTROL. MB Mfg. Co. Bulletins 616, 12 pp. Gives characteristics of Isomodes (MB's mountings for isolating the six modes of vibration) and a chart for locating the best mounting points.

(79) STABLE DC OSCILLOGRAPHS. Volkers & Schaffer Mfg. Corp. Sheet CC-702. Less than 1 millivolt of drift for practically unlimited periods of time and less than 2 min warm-up time are features of the new VS-900 "B" series of dc oscillographs.

(80) DIAPHRAGMS. Bellofram Corp. Catalog B. F. 150, 16 pp. Treats standard sizes, available materials, dimensions, and designs of long-stroke, deep convolution diaphragms. Loose-leaf format permits insertions.

(81) CATHODE-RAY OSCILLOGRAPHS. Du Mont Laboratories. Technical Sales Dept. Catalog, 8 pp. Data on low frequency, high frequency, and accessory instruments in this "Quick Reference Instrument Catalog" include technical features, applications, and prices.

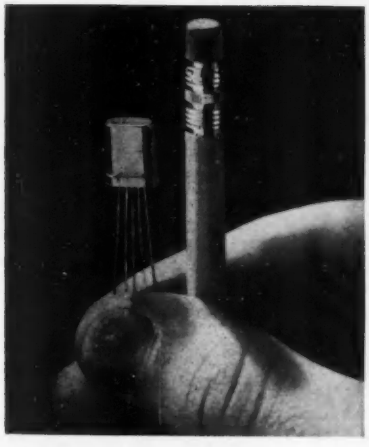
(82) TUBE BENDER. Parker Appliance Co., Catalog 1141A10. Feature here is a toggle clamp, which takes tubing of 1¼ in. O.D. without shoe inserts. Inserts can handle tubing sizes from ⅜ to 1¼ in. O.D.

(83) ELECTRONIC LINE. Chatham Electronics. Bulletin, 4 pp. Describes rectifiers, thyratrons, power triodes, voltage regulator reference tubes, etc. Each is shown above or alongside its respective specifications.

(84) RESOLVER AMPLIFIER. Norden-Ketay Corp. Bulletin 356, 1 p. A sealed enclosure of 2⅛ x 1⅛ x 1⅛ in. holds this single channel, electronic amplifier REA-4-110 which can realize a virtual infinite input impedance. The bulletin shows the unit in a system.

(85) ELECTRONIC TACHOMETER. Standard Electric Time Co. Bulletin 200-T, 4 pp. The folder is heavy with data about this minimum-tube, plug-in instrument that has a power requirement of 110 v, 60 cycles, and display time of .5 to 10 sec. Electrical signals may be pulses, sine waves, or square waves. The counter is accurate within one pulse.

(86) VARIABLE FREQUENCY POWER. Vectron, Inc. Special 1955 Show Bulletin, 1 p. This power supply unit tests, powers, and controls automatic equipment. Model VFS-250, 22 x 17 x 21 in., will fit on a standard 19 in. rack.



RELAY resists rattling in a pill-sized case.

This shock-resistant relay, housed in a standard transistor case, was designed for guided missiles where small size, weight, and vibration requirements prevail. A single pole double throw contact arrangement carries ¼ amp (~~non-inductive~~) in response to 100 milliwatts through the 26 vdc coil. *Elgin National Watch Co., Elgin, Ill.*

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High sensitivity combined with thorough wiping action is the forte of this relay. Silver contacts with sensitivity of only 10 milliwatts each, carrying up to 1 amp inductive, are used with coil resistance as high as 30,000 ohms. Hermetically sealed orders are welded. *Hedin Tele-Technical Corp., 640 W. Mt. Pleasant Ave. Livingston, N. J.*

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WHAT'S NEW ABSTRACTS

Get Rid of Interaction . . .

From "Improved Process Control from Noninteracting Controller Design," by D. P. Waite, Instrument Department, General Electric Co., West Lynn, Mass. ASME Paper No. 55—IRD-6

Nearly all three-term (proportional plus reset plus rate) controllers have interaction between the reset and rate actions. This is true for both pneumatic and electric controllers.

The interaction limits the ratio of actual rate time constant to actual reset time constant to a value less than 0.25. Some of the simpler controllers become unstable within themselves for ratios that approach this, further limiting usefulness.

A noninteracting controller was simulated on an analog computer by generating the rate and reset responses independently and adding them. This simulated controller had no limits on its rate to reset time constant ratios except those imposed by the finite ranges of the time constants.

Various process systems also were analoged on the computer and studied in combination with the controller analog. A systematic trial and error technique established the optimum settings for loop gain, reset time constant, and rate time constant. The criterion was the time integral of the absolute value of deviation from zero error following a step disturbance. It was computer-evaluated for speed.

First, a loop gain was assumed. Then the rate time constants were optimized for several values of reset time constants. The loop gain was changed and the process repeated until the minimum criterion value was found. If the optimum rate to reset time constant ratio thus found was greater than 0.25, then the criterion value was compared to that for the ratio restricted to 0.25.

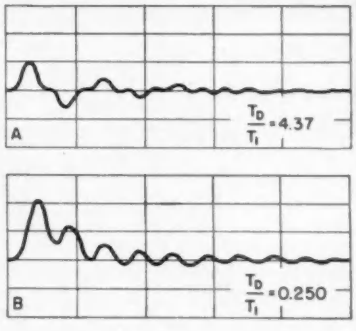
The same procedure was used to optimize the response for the ratio restricted to 0.25 as for the unrestricted case, except that for each reset time constant tried, the rate time constant had but one possible value.

The processes studied with the analog noninterinacting controller were:

- Three exponential lags and one dead time with three combinations of time constants (Cases 1, 2, and 3)
- Two exponential lags and one dead time (Case 4)
- Four exponential lags with two time constant combinations (Cases 5 and 6)
- Two exponential lags and one second-order feedback element with a damping factor of 0.8 (Case 7)

For each of these seven cases, optimum performance was reached from ratios greater than 0.25. The highest optimum ratio for the cases studied was 4.9 for Case 6. (The paper gives all pertinent time constants and gain settings.)

The analog computer result for Case 7 is illustrated. The optimum



rate to reset time constant ratio was found to be 4.37. It gave a computer-measured criterion value of 9.4 (area under curve A). Optimum conditions for the ratio restricted to 0.25 give a criterion value of 26.

Although not exhaustive, this computer investigation has proved that noninteracting controllers can improve the response of many process control systems. These computer studies will be continued for other process types.

. . . Here's One Approach

From "The Theory and Design of Compound-Action Pneumatic Controllers: with Particular Reference to the Interaction Factor," by H. Williamson, Negretti & Zambra, Ltd., "Transactions of the Society of Instrument Technology," December, 1954, London

Most pneumatic controllers that generate proportional plus reset plus rate functions of the input have interaction between the integral and derivative functions. This interaction produces an additional proportional response with a coefficient dependent on the integral and derivative time settings.

Some manufacturers calibrate the controller in arbitrary units and provide calibration curves to take the

interaction factor into account. Others build in a geared computer.

Setting of an interacting controller on the plant can be very difficult. Adjustment of any function modifies the other two and the response results from three variables instead of one.

A non-interacting controller avoids this problem.

This 12-page article develops thoroughly the design and theory of Negretti & Zambra's non-interacting proportional plus reset plus rate controller.

Towards Greater Flying Safety

From "The General Mills Ryan Flight Recorder," by J. J. Ryan, Mechanical Division, General Mills, Inc. ASME Paper No. 55—S-27

Here's an instrument that inscribes air speed, altitude, vertical acceleration, compass heading, and time for a complete aircraft performance record. A three-dimensional flight path can be determined from these records. The vertical acceleration record permits calculation of impact loads due to hard gusts or landing shocks. This calculation indicates how much maintenance inspection is necessary.

The recorder may reveal the cause of a crash since it can preserve data through 100-g impacts, half-hour exposure to 1,100 deg C gasoline flames, and 36-hour immersion in sea-water. And yet this is a sensitive instrument that measures within about 1 per cent.

The Civil Aeronautics Administration long has sought such an instrument to add to the knowledge of flight conditions and certify the reason for a crash. The recorder meets July, 1952 specifications of CAA-CAB. CAA may soon require these recorders on all passenger aircraft to supply statistics needed to find weak spots in aircraft design and suggest future development.

The recorder scribes its data on a 100-ft roll of 0.001-in. thick aluminum foil 2¼ in. wide. It can record continuously for 300 hours. The ribbon speed need not be constant because timing marks are recorded. So the take-up spool is driven at constant speed, and the ribbon speed varies between 3.2 and 5.5 in. per hr.

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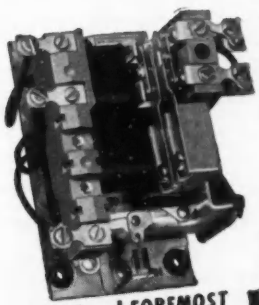

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Sales Engineer, Helipot Corporation

Reprinted from PRODUCT ENGINEERING:
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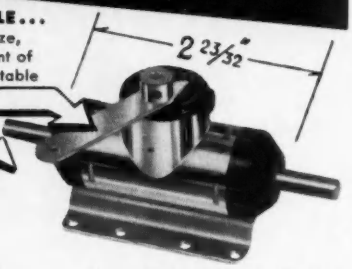

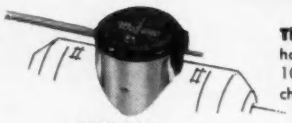

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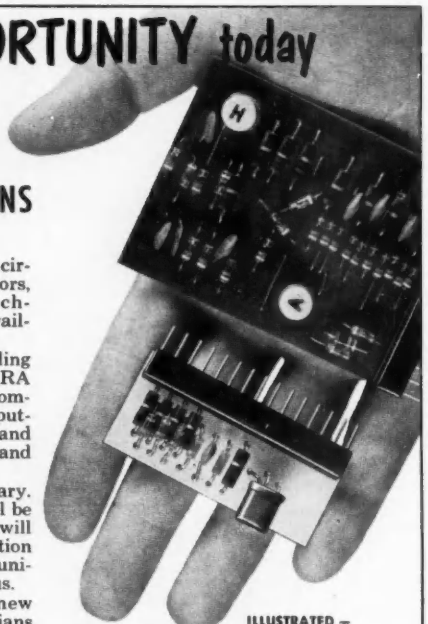

ILLUSTRATED — Designs for new Remington Rand ERA computers that are now under development. *Upper:* general purpose digit register. *Lower:* packaged transistor logic element.

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ABSTRACTS

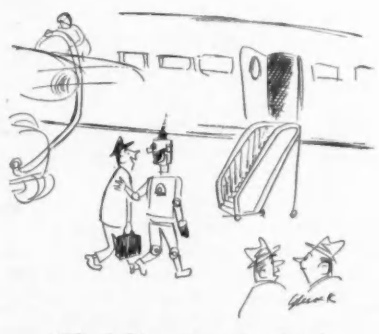
motor that runs on the airplane's 28-volt dc electric supply. The motor drives the spool through a clock escapement that acts as a governor; thus the motor need turn at only 6 revolutions per hour. The take-up spool runs at 1 rph. The motor is connected to the driving gears by a helical spring. If electric power fails, the spring has enough stored energy to drive the clockwork and recording rolls for at least ten minutes. A rachet and pawl prevent motor reversal on power failure.

Styli from the recording elements emboss continuous lines on the aluminum foil as it passes over a platen. These lines are about 0.002 in. wide. The styli are displaced, with respect to each other, in the time direction to preclude interference and minimize width of record.

Recorded data can be analyzed quickly with a transparent overlay chart positioned with respect to a scribed reference line and the time mark desired. The data record with the overlay in position can be photographed for enlargement and future analysis.

There are no switches or valves that can accidently disconnect the recorder. The master power switch in the cockpit energizes the recorder drive and the compass power when the pilot enters.

The pilot has, however, a push-button that makes a special-event mark on the record. Thus, any severe bump such as a hard landing may be noted by the pilot and especially evaluated for its effect on the aircraft. For example, a bump of 2 g may require that only part of the plane be inspected. But a 3-g bump might mean grounding and a thorough study into airworthiness.



"That's his automatic pilot—"

Reflections On Robots

From "The Age of the Thinking Robot, and What It Will Mean to Us," By Robert Bendiner. "The Reporter," April 7, 1955.

(This article rises out of the deluge of non-technical pieces on automatic control like cream out of milk. It is well worth a leisurely perusal.)

Experts, in aiming a fast camera at automatic control as it races along, disagree on its achievements to date. What no one can disagree on, however, is that the process is an entirely new thing—not an extension of the technological advancement of the past century.

Reception by both management and labor is mixed. Management revels in automatic control's promises of improved methods of production, but then, anticipating painful demands by labor, belittles it; labor sees it as a harbinger of plenty, but fears acute unemployment. When not belittling control, management's assurances to labor seem dangerously hazy and speculative.

Labor condemns the loss of skilled job classifications, the foresight of management in labeling an employee "temporary" so that a loophole exists for his discharge. Labor is not convinced that only large plants will adopt computers and in fact this is not so. Small companies *will* adopt computers. Labor sees signs of a hidden, creeping type of unemployment in all this and wonders how it will fare when the market is saturated with automatic equipment.

Labor, of course, has a responsibility to keep in step, too: a skilled electrician today will not stay "skilled" unless he learns about electronics. But this responsibility is shared by our educational system, which must condition executives to understand other fields besides technology: human relations, economics, psychology, and therefore, at last, philosophy.

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Servomechanisms and Regulating System Design

ENGINEERING CONTROL. *By Harold Chestnut and Robert W. Mayer, Volume II, 5½x8½ in. 384 pp. Published by John Wiley & Sons, Inc., New York. $8.50.*

A step from the first volume to the graduate and practicing engineer level, this book carries basic problems and theories of servomechanisms to advanced applications. Much of it deals with control problems at the grass-roots: 30 pages on specifics in selecting a power element for a controlled system; 31 pages on specific circuits for obtaining optimum attenuation-frequency characteristics; 37 on amplifiers; 119 on linearizing nonlinear elements for small or large departures; and 44 on applying nonlinear elements to control systems.

The opening 36 pages on measurement techniques and the subsequent 53 on the influence of input characteristics on control system design provide a fairly gentle introduction to the remainder of the book, which is intended to be of practical application value to men with specific problems. Shortcuts to measuring noise, obtaining frequency response from transient response to a unit input signal, and computation of frequency response from transient response to a bounded input signal are some of the practical matters discussed in the opening sections.

Charts and tables in abundance for such questions as motor-to-load gear ratio for minimum rms motor torque, and the influence of gear mesh ratios on motor time constant are typical. A series of charts on networks for obtaining desired attenuation-frequency is followed by examples of their use, along with circuit techniques for simplifying analysis. As might be expected, the bulk of the amplifier chapter deals with drift, its causes and cures. Such subjects as the use of ac tachometers for stabilization, jet engine control characteristics, backlash in positional controls with load resonance, relay servomechanisms, autopilot systems, computer systems and the use of nonlinear elements for changing system performance are dealt with thoroughly.

This work is organized so that many sections may be read independently, and in this respect it verges on an advanced control engi-

neering handbook. This is not a component catalog, however; it sticks to the systems. The authors are General Electric people in the Aeronautical and Ordnance Systems Div. Chestnut is in the marine systems engineering section of that division, and Mayer is a consulting engineer in the engineering section of the Guided Missiles Dept.

Higgins Reviews Thaler

ELEMENTS OF SERVOMECHANISM THEORY. *George J. Thaler, U. S. Naval Postgraduate School, 6 x 9 in., 282 pp. Published by McGraw-Hill Book Company, Inc., 330 W. 42d Street, New York 36, N. Y. $7.50*

The author remarks in his preface that "the material in this text is intended for a one-semester senior undergraduate course" and that it "was written with a threefold purpose:

1. It was desired to present the basic theory without using operational calculus or complex-variable theory, since these subjects are not normally given in an undergraduate engineering program.
2. The frequency-response methods were to be emphasized, since these are commonly used in practical engineering.
3. The polar and logarithmic approaches to analysis and design were to be integrated and compared.

The author feels that these purposes have been accomplished. . . ."

The reviewer is of the same opinion.

This text is well-written; style of presentation, clarity of expression, completeness of statement, and careful account of interlinking concepts are excellent. Each major theoretical development is supported by illustrative numerical examples. Discussion of particular systems is reinforced by pertinent industrial applications. The references, though few, are directly pertinent to the corresponding chapter—in welcome contrast to the long list of randomly chosen, nonintegrated items that comprise the several-paged "References" of many technical books.

Sets of exercise problems are included for seven of the twelve chapters. Assuming that in testing the material the author has worked each of these to insure accurate statement, that all necessary data are given, and that no excess data yielding ambiguous solution are given (to the reviewer's knowledge, these three specifications have not been satisfied in most

Continued on page 128

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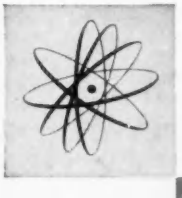

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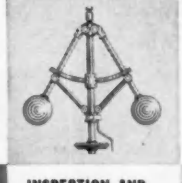

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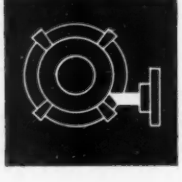

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control books), these problems appear sufficient in number and broad enough in scope. Student assignments can be shifted from term to term, and still afford review of all points of theory discussed in the text. Besides, in preparing these problems the author has, most considerately and effectively, adopted an admirable means of conserving the student's time.

". . . to minimize the over-all computation time . . . the author has utilized the problems at the end of Chapter 3 in setting up later problems" so "the student can use the results of previous work on each succeeding problem, which considerably reduces the over-all computation time" devoted to mere routine calculation.

Essential content and approximate degree of emphasis is indicated by the inclusive page numbers of the ten major chapters: Introduction (1-12); General Aspects of Analysis and Design (13-26); Transient Analysis of Servomechanisms (27-52); Transfer Functions (53-76); Transfer-Function Plots (77-97); Analysis of Single-Loop Systems (98-124); Methods of Meeting Performance Specifications (125-133); Gain Adjustment of Servomechanisms (134-143); Series Compensation of Servomechanisms (144-184); Feedback Compensation of Servomechanisms (185-216); and of two brief, descriptive chapters, Introduction to Advanced Topics—on Linear Theory and on Nonlinear Theory (217-246). Appendices on Tables of Numerical Data (247-250), Servo Components (251-262), An Introduction to the Laplace Transformation (263-278), and a detailed Index (279-282) round out the book.

A careful reading of the text, with attention to accuracy of theory, showed a number of errors. But these are such as to puzzle, rather than baffle, the reader—hence will work no considerable hardship on him. For they occur mainly in developments, and the end results are actually correct: for example, it is incorrect to equate the second and third expressions in equation (4-6), so the remainder of the development is incorrect; yet the result in equation (4-10) agrees with the corresponding member of the correct equation (4-13)!

The reviewer recommends this text to the engineer in industry who desires, through self-study to gain a basic grounding in modern servomechanism theory.

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Human Engineering Institute, Course in Human Engineering, Dunlap and Associates, Inc., Stamford, Conn. June 6-10

Society of Automotive Engineers, Golden Anniversary Summer Meeting, Atlantic City, N. J. June 12-17

American Institute of Electrical Engineers and American Physical Society, First Technical Conference and Exhibit on Magnetism, William Penn Hotel, Pittsburgh, Pa. June 14-16

American Society of Mechanical Engineers, Combustion Conference, IRD Session on Control of Industrial Furnaces, Massachusetts Institute of Technology, Cambridge, Mass. June 15-17

American Society of Mechanical Engineers, Diamond Jubilee Semi-Annual Meeting, IRD Session on Thermodynamics, Hotel Statler, Boston, Mass. June 19-23

American Institute of Electrical Engineers, Summer General Meeting, New Ocean House, Swampscott, Mass. June 27-July 1

AUGUST

American Institute of Electrical Engineers, Pacific General Meeting, Butte, Mont. Aug. 15-19

Stanford Research Institute and National Industrial Conference Board, Symposium on Electronics and Automatic Production, Civic Auditorium, San Francisco, Calif. Aug. 22-23

Western Electronics Show and Convention, San Francisco Civic Auditorium, San Francisco, Calif. Aug. 24-26

SEPTEMBER

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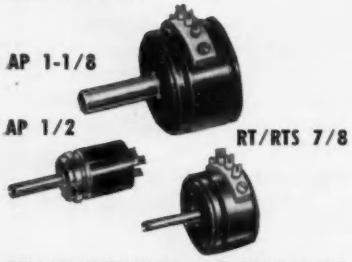

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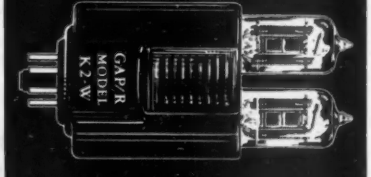

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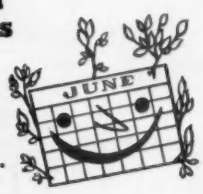

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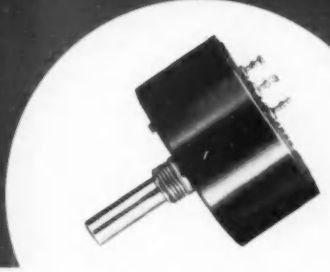

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This is a reproduction of an advertisement we are running in Business Week to reach people who do not read technical journals of the instrument industry.

Face up to AUTOMATION

let's take a few minutes to remove any mental block preventing you from a basic appreciation of the new concepts of data reduction and automation. Already you achieve an unbelievable amount of data processing in your own personal life: you combine information concerning your income, your required expenditures, the age and physical state of your car, your wife's feelings about style . . . and you process these data mentally to conclude that you will or will not buy a new car. The answer is not straight-forward, but it has its logic.

Similarly, data handling systems and data reduction systems supply *automatically* a humanly-determined logic to various pieces of information, and arrive at the compact answer which you—the process or manufacturing supervisor—feel is most important. You used to look at the information given by a heterogeneous collection of instruments measuring temperature, pressure, flow rates, tank levels, et cetera, and mentally decide whether or not the process was performing up to par: generally no one temperature or pressure or tank level was sufficient information. Nowadays, data handling systems can automatically "look" at these process variables for you, interpret them, and tell you *directly* whether or not the process is up to par—and if it isn't, the data handling systems can usually be made to tell you very specifically what to do to correct the inefficiencies.

You supply the logic

All that the data handling systems are doing, therefore, is automatically and consistently applying your logic to the available information from process or manufacturing operation to give you unhesitatingly—and directly—the specific answer you demand.

So much for data handling, data processing, or data reduction. Let's see if we can determine where the *automation* comes in.

Normally speaking, once you have analyzed the state of the process—either by evaluating the variables humanly, or by relying on an automatic data handling system—you must decide whether corrective action is necessary or whether the process is going along satisfactorily. If you do apply corrective action—you do so according to a logic which you have determined by experience. Both the decision to apply corrective action and the specific correction applied are logically arrived at.

Here's where automation can enter the picture. If you set up a system of automatic devices—a computer, more or less—to carry out the *logic* of "decision making" and "correction initiating," you have an automated process.

Realize that systems of data reduction or of automation are based on cold logic—there is no magic about them. *You* have to establish the logic, furthermore, before such systems can be effected. The systems merely save you the time and effort of repeating the logical reasoning and physical corrective action over and over again.

When do these systems become feasible?

Many such systems have been operating for years in certain fields of research, process operation, and factory production. When any information collecting and logical processing become repetitive—and when logical decisions and actions also become repetitive—data reduction and automation systems are generally possible. A thorough analysis of time and effort saved—of increased efficiency—will reveal the economic feasibility of such systems.

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